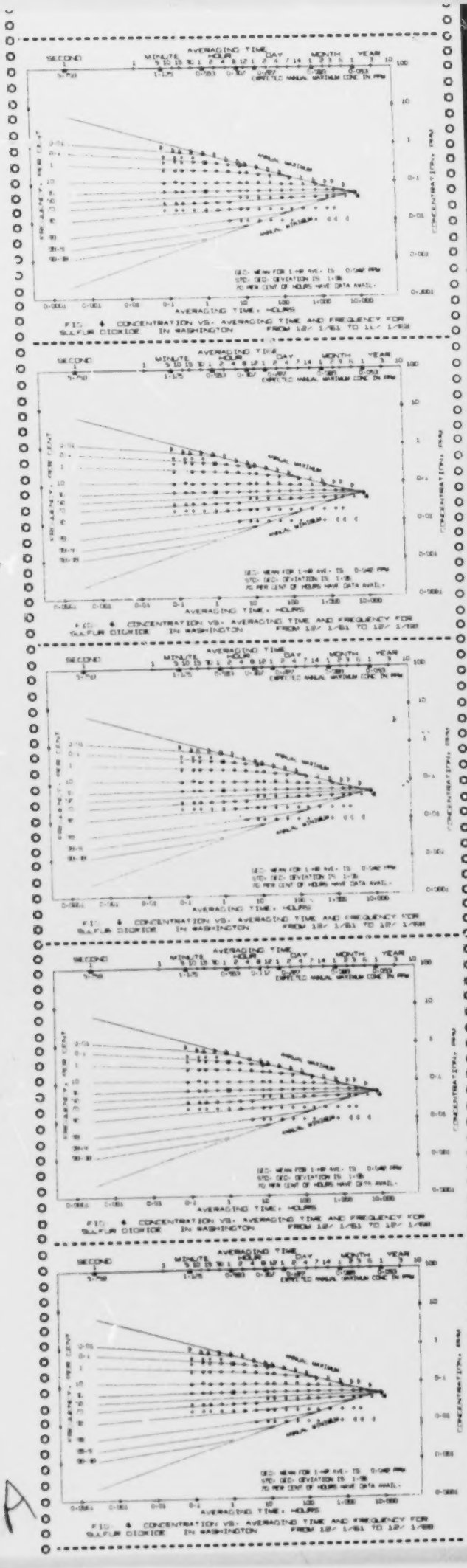

FIG. 4 CONCENTRATION VS. AVERAGING TIME AND FREQUENCY FOR SULFUR DIOXIDE IN WASHINGTON FROM 12/ 1/61 TO 11/ 1/62

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A MATHEMATICAL MODEL FOR RELATING AIR QUALITY MEASUREMENTS TO AIR QUALITY STANDARDS

U.S. ENVIRONMENTAL PROTECTION AGENCY

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BIBLIOGRAPHIC DATA SHEET	1. Report No. AP-89	2.	3. Recipient's Accession No.
4. Title and Subtitle A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards			5. Report Date November 1971 6.
7. Author(s) Ralph I. Larsen, Ph.D.			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Environmental Protection Agency Office of Air Programs Research Triangle Park, North Carolina 27711			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address Same as above			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstracts: Analyses of air pollution data indicate that air quality measurements tend to fit a general mathematical model having the following characteristics: pollutant concentrations are lognormally distributed for all averaging times; median concentrations are proportional to averaging time raised to an exponent; and maximum concentrations are approximately inversely proportional to averaging time raised to an exponent. The above characteristics have been used to develop equations that may be employed to calculate the geometric mean, standard geometric deviation, maximum concentration, and various percentile concentrations of air pollutants. To illustrate the predictive, as well as the interpretive value of the model, parameters have been first calculated for one averaging time from actual data and then calculated for other averaging times by means of the model. Maximum concentrations calculated with the model are compared with measured values for seven gaseous pollutants obtained during continuous sampling for up to 7 years in eight cities. Averaging times for which the model is most and least accurate are discussed. The analytic techniques described can be used to compare ambient pollutant concentrations with air quality standards and to calculate pollutant parameters for various averaging times. The resulting information can be used in developing implementation plans and emission standards. All the equations needed for performing the calculations are listed in the appendix.

17. Key Words and Document Analysis. 17a. Descriptors

Air pollution
Statistical analysis
Mathematical models
Criteria
Standards
Carbon monoxide
Hydrocarbons
Nitric oxide
Nitrogen dioxide
Nitrogen oxides
Sulfur dioxide
Oxidizers
Environmental surveys
Urban areas

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Superintendent of Documents Government Printing Office Washington, D. C. 20402 SOD No. EP 4.9:89	UNCLASSIFIED	64
	20. Security Class (This Page) UNCLASSIFIED	22. Price $0.60

FORM NTIS-35 (10-70)

USCOMM-DC 40329-P71

A MATHEMATICAL MODEL FOR RELATING AIR QUALITY MEASUREMENTS TO AIR QUALITY STANDARDS

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National Environmental Research Center

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR PROGRAMS
RESEARCH TRIANGLE PARK, NORTH CAROLINA
November 1971

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 60 cents

ACKNOWLEDGMENTS

Sincere gratitude is expressed to George Morgan, Gerald Nehls, Thomas Oliver, and their staff for providing the CAMP data listed herein; and to Gene Lowrimore for providing the exact computer solution for plotting position.

The AP series of reports is issued by the Environmental Protection Agency to report the results of scientific and engineering studies, and information of general interest in the field of air pollution. Information reported in this series includes coverage of intramural activities and of cooperative studies conducted in conjunction with state and local agencies, research institutes, and industrial organizations. Copies of AP reports are available free of charge—as supplies permit—from the Office of Technical Information and Publications, Office of Air Programs, Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

Office of Air Programs Publication No. AP-89.

ABSTRACT

Analyses of air pollution data indicate that air quality measurements tend to fit a general mathematical model having the following characteristics:

1. Pollutant concentrations are lognormally distributed for all averaging times.

2. Median concentrations are proportional to averaging time raised to an exponent.

3. Maximum concentrations are approximately inversely proportional to averaging time raised to an exponent.

The above characteristics have been used to develop equations that may be employed to calculate the geometric mean, standard geometric deviation, maximum concentration, and various percentile concentrations of air pollutants. To illustrate the predictive, as well as the interpretive value of the model, parameters have been first calculated for one averaging time from actual data and then calculated for other averaging times by means of the model. Maximum concentrations calculated with the model are compared with measured values for seven gaseous pollutants obtained during continuous sampling for up to 7 years in eight cities. Averaging times for which the model is most and least accurate are discussed.

The analytic techniques described can be used to compare ambient pollutant concentrations with air quality standards and to calculate pollutant parameters for various averaging times. The resulting information can be used in developing implementation plans and emission standards.

All the equations needed for performing the calculations are listed in the appendix.

Key Words: Air quality, statistical analyses, mathematical model, air quality criteria, ambient air quality standards, carbon monoxide, hydrocarbons, nitric oxide, nitrogen dioxide, nitrogen oxides, photochemical oxidants, sulfur dioxide.

TABLES

1. Relationship between Air Pollutant Exposure and Effects 3

2. National Primary and Secondary Ambient Air Quality Standards 5

3. Concentration (ppm) versus Averaging Time and Frequency for Sulfur Dioxide, Washington, D.C., December 1, 1961, to December 1, 1968 13

4. Carbon Monoxide Concentration (ppm) at CAMP Sites, by Averaging Time and Frequency, 1962 through 1968 14

5. Hydrocarbon Concentration (ppm) at CAMP Sites, by Averaging Time and Frequency, 1962 through 1968 16

6. Nitric Oxide Concentration (ppm) at CAMP Sites, by Averaging Time and Frequency, 1962 through 1968 18

7. Nitrogen Dioxide Concentration (ppm) at CAMP Sites, by Averaging Time and Frequency, 1962 through 1968 20

8. Nitrogen Oxides Concentration (ppm) at CAMP Sites, by Averaging Time and Frequency, 1962 through 1968 22

9. Oxidant Concentration (ppm) at CAMP Sites, by Averaging Time and Frequency, 1962 through 1968 . 24

10. Sulfur Dioxide Concentration (ppm) at CAMP Sites, by Averaging Time and Frequency, 1962 through 1968 26

11. Plotting Position of Extreme Concentrations and Percentiles for Selected Averaging Times 30

12. Standard Geometric Deviations at Which "Control" Switches from One Standard to Another 42

13. Slope of Maximum Concentration Line for 1-hour-average Standard Geometric Deviations from 1.0 through 4.99 45

14. Ratio of Expected Annual Maximum Pollutant Concentration to Arithmetic Mean Concentration for Various Averaging Times and Standard Geometric Deviations 46

FIGURES

1. Measured Ambient Air and Calculated Blood Carbon Monoxide Concentrations at the Lennox Site in Los Angeles County from October 26 through 28, 1965 4

2. Estimated Frequency of Hourly Temperatures at CAMP Site, Washington, D.C., December 1, 1961, to December 1, 1968 8

3. Frequency of 1-hour-average Sulfur Dioxide Concentrations Equal to or in Excess of Stated Values, Washington, D.C., December 1, 1961, to December 1, 1968. 11

4. Computer Plot of Concentration versus Averaging Time and Frequency for Sulfur Dioxide at Site 256, Washington, D.C., December 1, 1961, to December 1, 1968 36

5. Expected Annual Maximum Sulfur Dioxide Concentrations at Sampling Site Where National Secondary 3- and 24-hour-standard Concentrations Occur Once a Year 40

CONTENTS

INTRODUCTION 1

EFFECTS VARIABLES 3
- Exposure Duration 3
- Frequency 4

AIR QUALITY STANDARDS 5

FREQUENCY ANALYSES 7
- Normal Frequency Distribution 7
- Lognormal Distribution 9
- Cumulative Frequency Distribution 10
- Comparing Data with Standards 12
- Calculating the Standard Geometric Deviation 28
- Calculating the Geometric Mean 29
- Calculating the Expected Annual Maximum Concentration 31
- Using Non-Continuous Data 32

AVERAGING-TIME ANALYSES 35
- A Mathematical Model 35
- Calculating the Standard Geometric Deviation 37
- Calculating the Geometric Mean 42
- Plotting Results 43
- Short-Cuts 44
- Non-Lognormally Distributed Data 45

SUMMARY 49

APPENDIX: WORKING EQUATIONS AND EXERCISES WITH ANSWERS 51
- Equations 51
- Exercises 52
- Answers 53

REFERENCES 55

A MATHEMATICAL MODEL FOR RELATING AIR QUALITY MEASUREMENTS TO AIR QUALITY STANDARDS

INTRODUCTION

The setting of air quality standards is one of the major steps toward controlling widespread pollutants. In the United States, the Federal Government sets national minimum air quality standards for such pollutants,[1] but the states may set more stringent standards if they wish. The major purpose of air quality standards is to prevent the occurrence of adverse effects such as those described in air quality criteria documents.[2-5]

In the criteria documents and in the national ambient air quality standards, allowable levels of air pollution are expressed in terms of the concentration of a specific pollutant and the duration of exposure to that pollutant. Some air quality data cannot be compared directly to such standards, however, because pollutants are sampled and analyzed by many different techniques and are sampled and averaged over different time periods (averaging times). Nonetheless, a basis for reduction to uniformity exists inasmuch as air quality data tend to fit a mathematical model having the following characteristics:

1. Pollutant concentrations are lognormally distributed for all averaging times.

2. Median concentrations are proportional to averaging time raised to an exponent.

3. Maximum concentrations are approximately inversely proportional to averaging time raised to an exponent.

These characteristics have been used to develop equations, given in this report, that can be used to calculate the following air pollutant parameters, regardless of averaging time used: geometric mean, standard geometric deviation, maximum concentration expected once a year, and frequency distribution of expected pollutant concentrations.

The mathematical model presented in this report can be used not only for reducing real data, but also for predicting pollutant concentrations; that is, parameters calculated for one averaging time from actual data can be calculated for other averaging times by means of the model. Consequently, the model can be used for interpretation, comparison, and prediction.

When the model is used to achieve comparability of air quality data, ambient pollution concentrations can be compared directly with air quality standards. The resulting information can be used in the development of emission control strategies and implementation plans.

The following sections present the model and illustrate its interpretive and predictive value through sample calculations and the treatment of real data.

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EFFECTS VARIABLES

EXPOSURE DURATION

The exposure time required to cause a particular pollutant effect depends upon the type of effect (Table 1). Odor, for instance, can be detected in a 1-second whiff.[6] On the other hand, a much longer exposure to carbon monoxide is required to cause a different type of effect, impaired judgment. An 8-hour exposure to a carbon monoxide concentration of 12 to 17 milligrams per cubic meter, mg/m^3 (10 to 15 parts per million, ppm) can impair a person's judgment of time intervals.[2] Vegetation can be damaged by an exposure of less than 1 hour if the concentrations of oxidant, sulfur dioxide, or some other toxicant are high enough; however, because of the pattern of pollutant concentration variation in urban atmospheres, plant damage is usually caused instead by long exposure (such as 8 hours) to low concentrations.

Table 1. RELATIONSHIP BETWEEN AIR POLLUTANT EXPOSURE AND EFFECTS

Approximate exposure duration	Effect	Pollutant			
		Carbon monoxide	Oxidant	Particulate matter	Sulfur oxides
1 sec	Sensation	--	x	--	x
	Odor	--	--	--	x
	Taste	--	x	--	--
	Eye irritation				
1 hr	Student athlete performance impaired	--	x	--	--
	Visibility reduced	--	x	x	x
8 hrs	Judgment impaired	x	--	--	--
	Heart patients stressed	x	--	--	--
	Vegetation damaged	--	x	--	x
1 day	Health impaired	--	--	x	x
	Soiling	--	--	x	--
4 days	Health impaired	--	--	--	x
1 yr	Health impaired	--	--	x	x
	Vegetation damaged	--	--	x	x
	Corrosion	--	--	x	x
	Soiling	--	--	x	--

It is apparent from Table 1 that in order to relate pollutant effects to pollutant concentrations, the concentrations should be analyzed as a function of exposure duration. This can be accomplished by averaging ambient pollutant concentrations over time periods such as an hour, a day, or a year.

The close agreement between ambient concentrations and a particular effect, when the appropriate averaging time is used, is shown in Figure 1.[7] The highest ambient 8-hour-average carbon monoxide concentration for a day agrees very closely with the highest carbon monoxide concentration expected in a man's blood stream for that day. The maximum 1-hour ambient value, however, is a poor indicator of expected blood levels, for it fails to show the relatively slow absorption and desorption of carbon monoxide that occurs over long periods.

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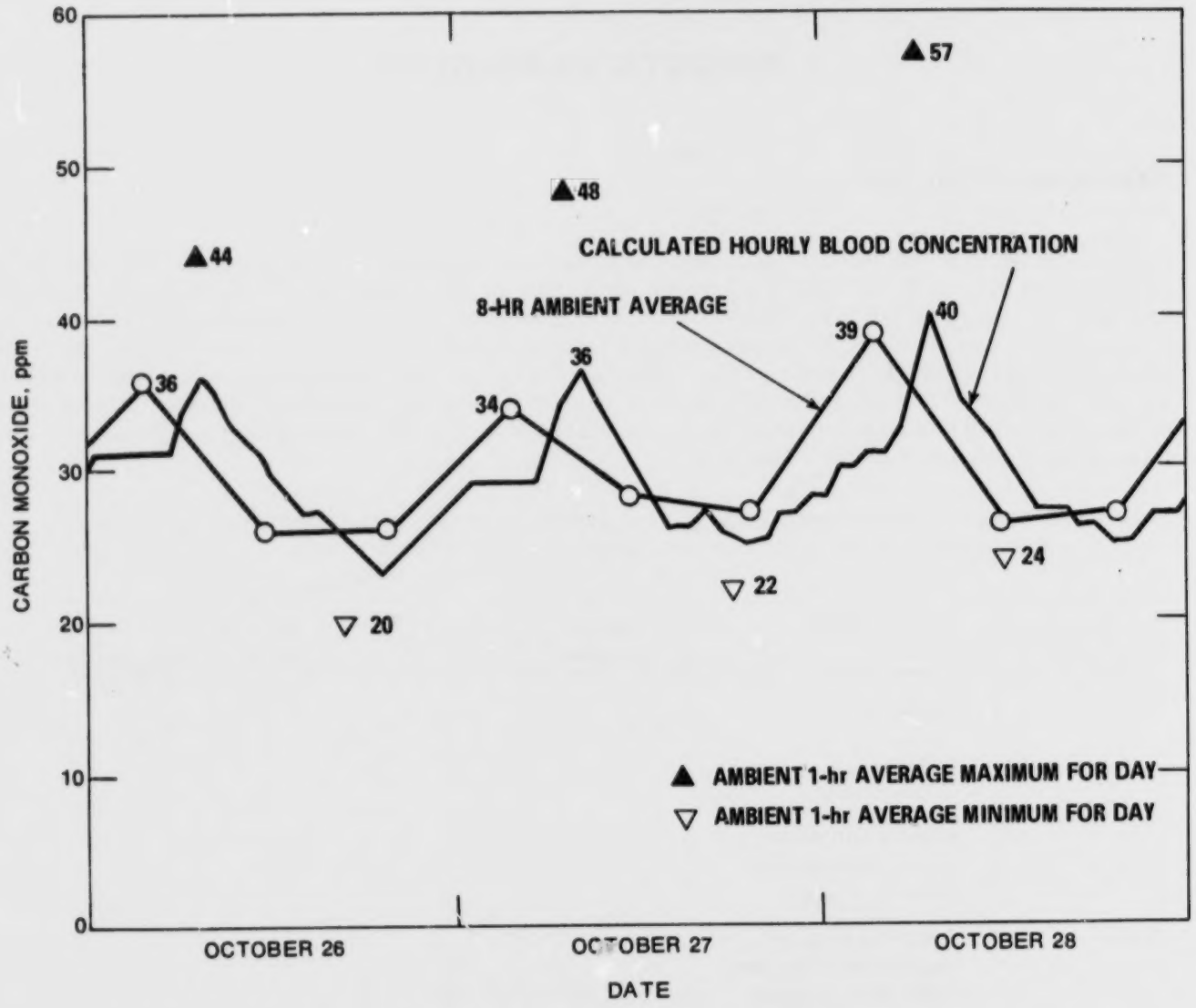

Figure 1. Measured ambient air and calculated blood carbon monoxide concentrations at the Lennox site in Los Angeles County from October 26 through 28, 1965.

FREQUENCY

Air pollutant concentrations vary as a function of meteorology and the number, strength, and location of sources relative to a particular air sampling site. The frequency with which a particular pollutant concentration is exceeded determines the frequency with which a particular effect can be expected. For example, the odor threshold concentration for a particular pollutant at a particular location might be exceeded 1 percent of the time. This frequency might not sound very objectionable but since an odor can be detected in a 1-second whiff, the odor might be smelled every few minutes.

Similarly, pollutant concentration data can be related to the frequency that plant damage might be expected.[8] Since commercial crops or ornamental plants can be permanently damaged by one exposure, damage might be expected if a damaging concentration were exceeded even once a year.

In order to relate air pollutant concentrations to effects, air quality data should be analyzed as a function of both averaging time and frequency.[9]

AIR QUALITY STANDARDS

As mentioned earlier, the Federal Government sets minimum air quality standards for certain pollutants, although the states may set more stringent standards if they wish. National primary ambient air quality standards are set to protect the public health and secondary standards are set to protect the public welfare. Such primary and secondary standards have been set for carbon monoxide, hydrocarbons, nitrogen dioxide, photochemical oxidants, particulate matter, and sulfur dioxide (Table 2).[1] Each standard specifies an averaging time, frequency, and concentration. The averaging times are 1, 3, 8, and 24 hours, and 1 year. The frequency parameter column of Table 2 specifies either annual maximum concentrations for averaging times of 24 hours or less, or an arithmetic or geometric mean for a 1-year period. The standards specify that the maximum concentrations are not to be exceeded more than once per year.

In order to relate measured air pollutant concentrations to air quality standards, measured concentrations must be expressed as a function of averaging time and frequency. The next two major sections will deal with the calculations needed to accomplish this task. The first major section will treat the frequency parameter. The second major section will treat the averaging-time parameter.

Table 2. NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS[1]

Pollutant	Type of standard	Averaging time	Frequency parameter	Concentration	
				$\mu g/m^3$	ppm
Carbon monoxide	Primary and secondary	1 hr	Annual maximum[a]	40,000	35
		8 hr	Annual maximum	10,000	9
Hydrocarbons (nonmethane)	Primary and secondary	3 hr (6 to 9 a.m.)	Annual maximum	160[b]	0.24[b]
Nitrogen dioxide	Primary and secondary	1 yr	Arithmetic mean	100	0.05
Photochemical oxidants	Primary and secondary	1 hr	Annual maximum	160	0.08
Particulate matter	Primary	24 hr	Annual maximum	260	--
		24 hr	Annual geometric mean	75	--
	Secondary	24 hr	Annual maximum	150	--
		24 hr	Annual geometric mean	60[c]	--
Sulfur dioxide	Primary	24 hr	Annual maximum	365	0.14
		1 yr	Arithmetic mean	80	0.03
	Secondary	3 hr	Annual maximum	1,300	0.5
		24 hr	Annual maximum	260[d]	0.1[d]
		1 yr	Arithmetic mean	60	0.02

[a] Not to be exceeded more than once per year.
[b] As a guide in devising implementation plans for achieving oxidant standards.
[c] As a guide to be used in assessing implementation plans for achieving the annual maximum 24-hour standard.
[d] As a guide to be used in assessing implementation plans for achieving the annual arithmetic mean standard.

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FREQUENCY ANALYSES

In order to make this discussion more meaningful, statistical parameters and specific examples are considered together. Example data have been drawn from past studies in which concentrations have been expressed as parts per million (ppm). Concentrations determined in future studies and analyses may tend to be reported in micrograms per cubic meter ($\mu g/m^3$).

NORMAL FREQUENCY DISTRIBUTION

Let us begin the discussion of frequency with an example. Assume that ambient temperature has been recorded each hour at the Continuous Air Monitoring Program (CAMP) site operated by the Federal air pollution control agency in downtown Washington, D.C. The estimated number of hours during the period from December 1, 1961, to December 1, 1968, that the hourly average temperature was a particular value has been plotted on Figure 2. A December 1 starting date has been selected so that the three coldest months, December, January, and February, could be kept together for calculating seasonal averages.

The data can be characterized mathematically by taking moments. A moment is merely a weight multiplied by a lever arm to a power. The first moment can be calculated about 0°F. In this case, the weight is the number of hours and the lever arm is temperature. Since 40°F occurred for an estimated 860 hours during this period, the moment at 40°F is 34,400. To obtain the arithmetic mean temperature, all of the moments for all of the temperatures are added and then divided by the number of hours for which observations are available. The same result could be obtained by adding all of the hourly observations together and dividing by the number of observations.

$$m = \frac{\sum x}{n} \qquad (1)$$

where m = the arithmetic mean,

$\sum x$ = the summation of all the temperature values, and

n = the number of temperatures observed.

For the example given,

$$m = \frac{3{,}495{,}000}{61{,}320}$$

$$m = 57°F$$

This calculation gives a very useful parameter, the arithmetic mean temperature at the Washington CAMP site; but it does not tell how much the temperature fluctuates about the mean. For that information, a second parameter is needed. The second moment about the mean can be calculated and used as follows:

$$s = \left(\frac{\sum x^2}{n}\right)^{0.5} \qquad (2)$$

where s = the standard deviation,

$\sum x^2$ = the summation of the squares of each observed temperature minus the mean temperature, and

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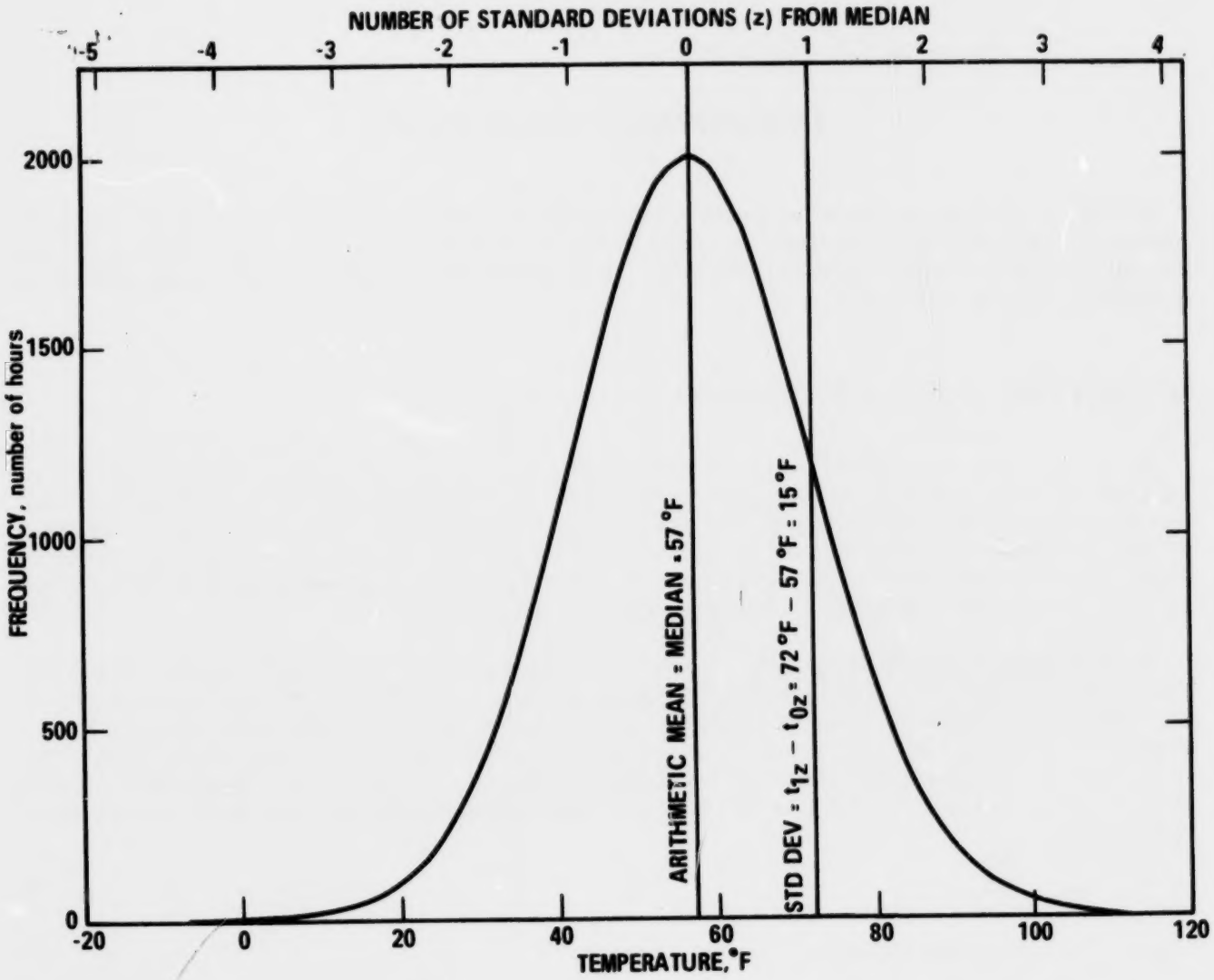

Figure 2. Estimated frequency of hourly temperatures at CAMP Site, Washington, D.C., December 1, 1961, to December 1, 1968.

n = the number of observations.

For the example given,

$$s = \left(\frac{13{,}800{,}000}{61{,}320}\right)^{0.5} \tag{3}$$

$$s = 15°F \tag{4}$$

This processed second moment, the standard deviation, indicates how much the temperature fluctuates about the mean. If the temperature were always the same, the standard deviation would be zero. If the temperature fluctuated widely, then the standard deviation would be very large. Two parameters can thus be used to characterize temperature at the Washington CAMP site, a mean and a standard deviation.

Figure 2 is plotted as if temperature followed a normal frequency distribution. Because the distribution of many variables tends to approximate this typical, bell-shaped plot, the number of samples expected for each value can be expressed by the normal, or Gaussian, equation:

$$y = \frac{n}{s(2\pi)^{0.5}} \exp\left[-0.5\left(\frac{x - m}{s}\right)^2\right] \quad (5)$$

where y = the number of samples expected to have a certain x-value (e.g., $x = 40^\circ$F, ranging from 39.50 to 40.50°F),

n = the total number of samples,

s = the standard deviation,

exp = the base of natural logarithms, 2.718, raised to the power that follows in brackets,

x = the value for which the frequency is desired, and

m = the arithmetic mean.

As one example, the number of hours when an observation of 40°F would be expected can be calculated.

$$y = \frac{61{,}320}{15(2\pi)^{0.5}} \exp\left[-0.5\left(\frac{40 - 57}{15}\right)^2\right] \quad (6)$$

$$y = 858 \text{ hours} \quad (7)$$

Equation 5 gives the number of samples with a given x-value. To determine the number of samples at or above a particular x-value, all of the calculated values of y for all values of x at and above the selected value are merely added together. Equation 5 can be integrated to accomplish this.

The area under any normal curve (Figure 2) can be set equal to unity or to 100 percent. Statistical texts tabulate cumulative frequency as a function of the number of standard deviations by which a particular x-value deviates from the median value. This type of information can be used to plot the *cumulative frequency distribution* for a particular set of data, a type of distribution that will be discussed later.

LOGNORMAL DISTRIBUTION

Sulfur dioxide concentrations at the Washington CAMP site have been measured and recorded on computer-readable punched paper tape every 5 minutes since shortly after December 1, 1961. If half or more of the 5-minute measurements, or 6, were available for an hour and considered valid, an hourly average was computed by adding the 5-minute observations available for that hour, dividing by the number of observations, and rounding the quotient.

If hourly sulfur dioxide concentrations were plotted using axes similar to those in Figure 2, they would not produce a frequency distribution of the same shape. The left tail would be quite short, the hump would be skewed to the left, and the right tail would be very long. Such a shape indicates that many concentrations are close to zero and that a few are very high. Unlike temperature, the sulfur dioxide values are blocked on the left, for they cannot go below zero. This left-skewed distribution often results when many values are close to zero. It can be readily normalized to the symmetrical curve shown in Figure 2 by plotting the frequency distribution of the logarithms of the concentrations rather than the concentrations themselves. Equations 1, 2, and 5 can also be normalized by replacing the concentration values with the logarithms of those values. Anti-logarithms can then be calculated to obtain *the two parameters needed to describe a lognormal distribution, the geometric mean and the standard geometric deviation.*

$$m_g = \exp\left(\frac{\sum \ln c}{n}\right) \tag{8}$$

$$s_g = \exp\left[\frac{\sum (\ln c - \ln m_g)^2}{n}\right]^{0.5} \tag{9}$$

where m_g = the geometric mean,

exp = the base of natural logarithms, 2.718, raised to the power that follows in brackets,

$\sum \ln c$ = the summation of the logarithms of the concentrations,

n = the number of observations, and

s_g = the standard geometric deviation.

For a lognormal distribution, the arithmetic mean (m), geometric mean (m_g), standard deviation (s), and standard geometric deviation (s_g) are related as follows:[10,11]

$$s_g = \exp\left[\ln^{0.5}\left(\frac{s^2}{m^2} + 1\right)\right] \tag{10}$$

$$m_g = \frac{m}{\exp(0.5 \ln^2 s_g)} \tag{11}$$

Or, taking logarithms:

$$\ln m_g = \ln m - 0.5 \ln^2 s_g \tag{12}$$

Rearranging to solve for $\ln m$ gives:

$$\ln m = \ln m_g + 0.5 \ln^2 s_g \tag{13}$$

CUMULATIVE FREQUENCY DISTRIBUTION

A plot like Figure 2 gives little more than a qualitative idea of the distribution of pollutant concentrations. The data could be evaluated much more easily if they were plotted so that a straight line is produced when the data are lognormally distributed. On log-probability graph paper, concentration is plotted on a logarithmic ordinate and the cumulative frequency distribution is plotted on the abscissa (Figure 3). The special probability scale used on the abscissa will produce a straight line when the data are perfectly lognormally distributed.

Because the most valuable information is how often air pollutant concentrations equal or exceed certain values, rather than how often concentrations are less than those values, the abscissa values in Figure 3 are used to represent the frequency with which a certain concentration is equaled or exceeded. These data are from Table 3.

The following equation is used to determine which observation should be plotted at a particular frequency:

$$r = \frac{fn}{100\%} + 0.999 \tag{14}$$

where r = the rank order of the observation, ranked from highest to lowest (r is truncated to give an integer value),

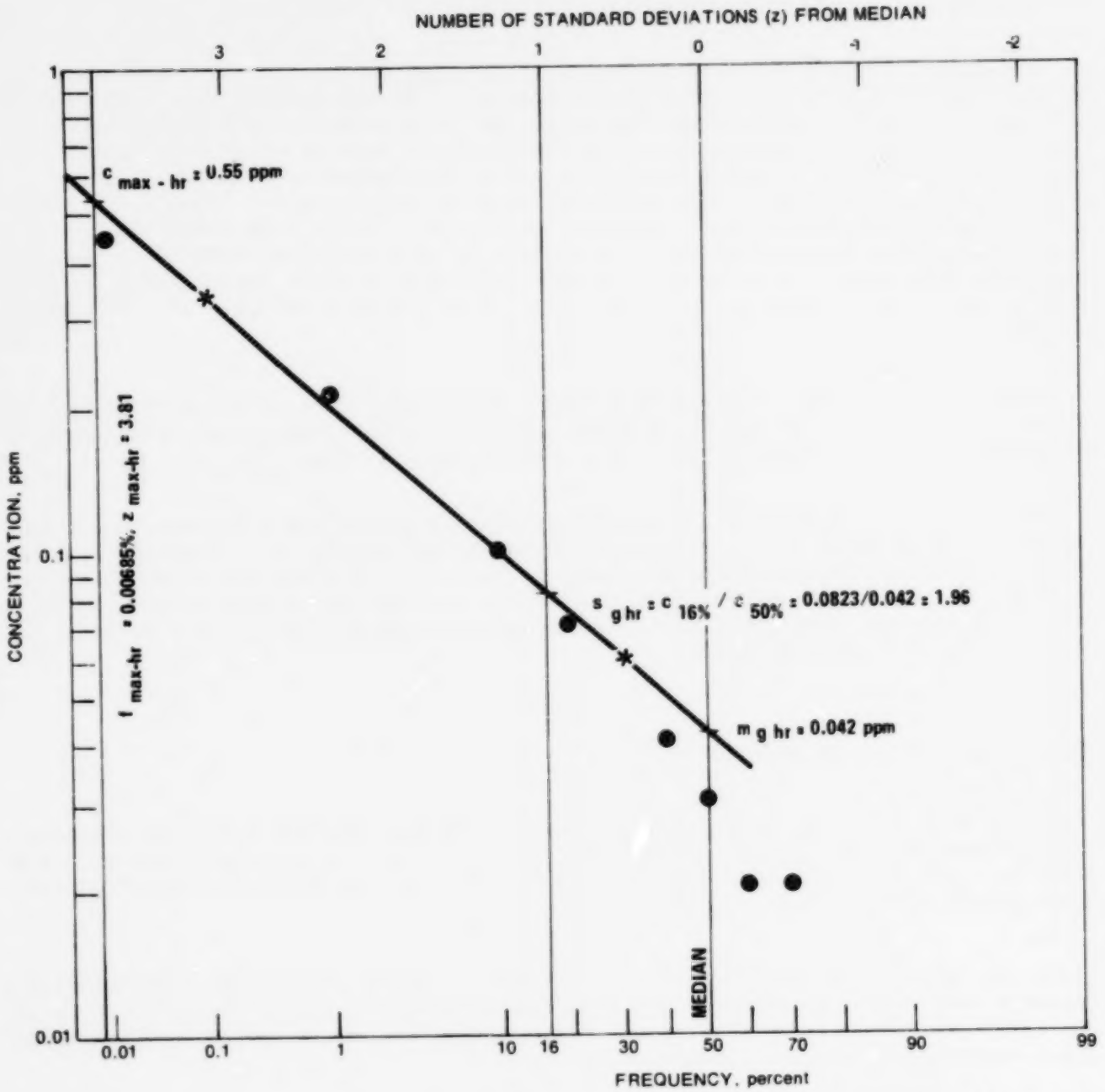

Figure 3. Frequency of 1-hour-average sulfur dioxide concentrations equal to or in excess of stated values, Washington, D.C., December 1, 1961, to December 1, 1968.

f = the selected frequency, in percent,

n = the number of observations, and

0.999 = a constant slightly less than 1, used to give uniform computer results.

If only one sample were available, such as a 1-year average for 1 year of data, then that concentration would be plotted at the 50-percent frequency. If two samples were available, such as two 6-month averages for 1 year of

data, then the high value would be plotted for frequencies below 50.05 percent and the low value would be plotted for frequencies at and above 50.05 percent.

The frequency distribution for the 1-hour averages in Table 3 was obtained as follows. Column 5 of Table 3 indicates that sulfur dioxide concentration data were available from the Washington CAMP site for 70 percent of the 61,300 hours in the 7-year period from December 1, 1961, to December 1, 1968, a total of about 43,000 hours. The hourly concentrations were arrayed from the highest to the lowest. A frequency of 0.1 percent is one of the first listed for 1-hour averages in the table. Substitution of that frequency in Equation 14 gives 43. The 43rd value in the array was thus selected as the point for the 0.1 percent frequency. This value, 0.34 ppm, is listed in Table 3 and plotted in Figure 3. This process was continued for each of the percentiles listed in Table 3. All of the numbers in the array were then added together; the resulting sum was divided by the number of observations and rounded to obtain the arithmetic mean of 0.05 ppm (column 2). The top value in the array is listed in column 3 as the maximum 1-hour-average concentration, 0.62 ppm. The bottom value in the array is listed in column 4 as the minimum concentration, 0.

CAMP information similar to that in Table 3 has been summarized in Tables 4 through 10 for the 7-year period and for each individual year in that period for carbon monoxide, hydrocarbons, nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen oxides ($NO + NO_2$), oxidants, and sulfur dioxide.

The last 9 columns under Washington in Table 10 have been extracted from Table 3. Maximum concentrations for each year are also shown. Column 5 in Table 10 indicates that the maximum 1-hour concentration measured during the 7 years was 0.62 ppm. Column 9 indicates that it occurred in 1964 (December 1, 1963, to December 1, 1964). Column 6 indicates that the lowest annual maximum concentration measured was 0.35 ppm, which occurred the next year, 1965. The highest annual maximum concentration during this 7-year period was thus about twice the lowest annual maximum.

COMPARING DATA WITH STANDARDS

Sulfur dioxide will be used as an example pollutant in the discussion that follows. The national secondary standards for sulfur dioxide specify an annual arithmetic mean, and maxima for averaging times of 3 and 24 hours. Some state standards specify a 1-hour maximum. Aerometric data analyses are needed that will accurately depict statistical parameters for all of these averaging times.

The first task is to calculate the two parameters needed to describe 1-hour-average concentrations as a lognormal distribution, *the geometric mean and the standard geometric deviation. The goal is to use the distribution data to calculate these parameters so that they in turn can be used to calculate expected concentrations for comparison with standards.*

As Figure 3 indicates, a lognormal distribution can be expressed as a straight line. A straight line, in turn, can be characterized by two parameters, an intercept and a slope. The intercept in this case is the point where the distribution line crosses the 50th percentile. This is the geometric mean or median. The slope is related to the standard geometric deviation. The standard geometric deviation can be calculated as the 16-percentile concentration (one standard deviation from the median, top abscissa on Figure 3) divided by the 50-percentile concentration.

As noted, *the geometric mean concentration for a lognormal distribution falls at the median or 50-percentile point.* Half of the concentration values are larger than the median and half are smaller. The arithmetic mean concentration falls near the 30-percentile point for aerometric data, however, because of the heavier weight of high concentration values in the calculation of arithmetic means. Thus, a distribution line drawn through the 30-percentile point for 1-hour averages should accurately estimate the arithmetic mean.

Table 3. CONCENTRATION (ppm)VERSUS AVERAGING TIME AND FREQUENCY FOR SULFUR DIOXIDE, WASHINGTON, D.C., DECEMBER 1, 1961, TO DECEMBER 1, 1968

Averaging time	Arithmetic mean	Max	Min	Percent data	Percent of time concentration is equaled or exceeded																
					0.001	0.01	0.1	1	10	20	30	40	50	60	70	80	90	99	99.9	99.99	99.999
5 min	0.05	0.87	0.00	70	0.65	0.49	0.35	0.21	0.10	0.07	0.06	0.04	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00
10	0.05	0.72	0.00	70	0.66	0.47	0.36	0.21	0.11	0.08	0.06	0.04	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00
15	0.05	0.68	0.00	70		0.47	0.35	0.21	0.10	0.07	0.06	0.04	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	
30	0.05	0.68	0.00	70		0.46	0.35	0.21	0.10	0.08	0.06	0.04	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	
1 hr	0.05	0.62	0.00	70		0.45	0.34	0.21	0.10	0.07	0.06	0.04	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	
2	0.05	0.55	0.00	70			0.32	0.21	0.10	0.08	0.06	0.04	0.03	0.03	0.02	0.01	0.00	0.00	0.00		
4	0.05	0.41	0.00	70			0.29	0.20	0.10	0.08	0.06	0.05	0.03	0.03	0.02	0.01	0.01	0.00	0.00		
8	0.05	0.35	0.00	71			0.26	0.18	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.01	0.01	0.00	0.00		
12	0.05	0.30	0.00	72			0.25	0.18	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.01	0.01	0.00			
1 day	0.05	0.25	0.00	72				0.16	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.01	0.01	0.00			
2	0.05	0.22	0.00	68				0.14	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.01	0.01	0.00			
4	0.05	0.18	0.00	71				0.14	0.09	0.08	0.06	0.05	0.04	0.03	0.02	0.01	0.01	0.00			
7	0.05	0.13	0.00	73					0.09	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01				
14	0.05	0.13	0.00	74					0.09	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01				
1 mo	0.05	0.11	0.00	76					0.09	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01				
2	0.04	0.10	0.01	74					0.08	0.08	0.06	0.04	0.04	0.03	0.02	0.02	0.01				
3	0.05	0.10	0.01	82						0.07	0.06	0.05	0.04	0.03	0.02	0.02					
6	0.04	0.08	0.01	93							0.06	0.05	0.04	0.04	0.03						
1 yr	0.05	0.05	0.04	86									0.04								

Table 4. CARBON MONOXIDE CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
CHICAGO																					
5 min	81	12.1	1.54	78	43	43	50	64	61	78	63	57	55	56	44	33	21	15	10	6	3
1 hr	53	12.3	1.46	59	28	28	36	46	44	59	56	40	56	51	40	30	21	15	10	7	3
8 hr	38	12.5	1.40	44	20	20	22	35	37	44	33	33	57		34	27	20	14	10	7	4
1 day	32	12.6	1.36	33	16	17	19	27	32	33	23	16	58			25	20	14	10	7	5
1 mo	18	13.0	1.22	21	7	7	10	17	21	18	11	7	62				18	13	10	7	6
1 yr	13	13.2	1.00	17	6			12	17	13		6	57						12		
CINCINNATI																					
5 min	103	4.0	2.09	50	26			26	50	32	47	46	70	40	32	16	9	6	5	3	2
1 hr	52	4.3	1.92	42	20			22	34	20	27	42	71	36	32	15	9	6	5	4	2
8 hr	29	4.5	1.77	36	12			19	21	12	17	36	72		32	14	8	6	5	4	2
1 day	22	4.6	1.69	32	9			17	16	9	13	32	74			14	8	6	5	4	3
1 mo	9	5.0	1.41	11	5			11	5	7	8	8	77				7	6	5	4	3
1 yr	5	5.3	1.00	6	4			6	4	5	5	6	100						5		
DENVER																					
5 min	114	6.4	1.93	90	63				70	73	63	90	72	62	44	26	13	9	6	4	2
1 hr	61	6.7	1.79	79	40				40	55	43	79	72	53	40	24	13	9	6	4	2
8 hr	37	6.9	1.66	30	27				27	29	30	29	74		29	18	12	8	6	5	3
1 day	28	7.1	1.60	21	16				16	20	20	21	76			16	11	8	7	5	4
1 mo	12	7.5	1.35	12	9				10	12	10	9	81				9	8	7	6	4
1 yr	8	7.9	1.00	8	5				7	8	8	5	100						7		
LOS ANGELES																					
5 min	72	9.5	1.58	81	70	81	70	75					79	50	36	25	16	12	10	9	7
1 hr	46	9.7	1.50	47	35	43	35	47					79	43	34	25	16	12	10	9	7
8 hr	32	9.9	1.43	28	27	28	28	27					81		27	21	15	12	10	9	8
1 day	26	10.0	1.39	23	22	22	22	23					82			19	15	12	11	9	8
1 mo	15	10.3	1.24	14	13	14	13	14					89				13	12	11	9	9
1 yr	11	10.6	1.00	11	9	11	9	11					100						11		

[a]Standard geometric deviation.

Table 4 (Continued). CARBON MONOXIDE CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
PHILADELPHIA																					
5 min	83	6.7	1.77	67	43	51	52	43	67	47	44	49	58	47	35	22	13	9	7	5	3
1 hr	48	6.9	1.66	54	35	47	47	37	54	43	42	35	58	45	33	22	13	9	7	5	3
8 hr	31	7.1	1.56	36	23	36	35	27	26	34	23	26	59		27	20	12	9	7	5	3
1 day	24	7.2	1.50	25	14	23	25	21	19	20	14	23	60			18	12	9	7	6	4
1 mo	12	7.6	1.30	14	9		14	13	11	10	9	11	62				10	8	7	6	5
1 yr	8	7.9	1.00	8	6			7	8	7	6	8	71						7		
ST. LOUIS																					
5 min	50	5.4	1.65	68	45			45	53	68	60	47	86	42	30	19	10	7	5	4	2
1 hr	31	5.6	1.56	29	25			25	27	29	27	26	87	27	22	17	10	7	5	4	2
8 hr	21	5.7	1.48	18	12			18	18	18	14	12	88		17	13	9	7	5	4	3
1 day	17	5.7	1.43	17	9			17	15	12	11	9	89			12	9	7	6	5	3
1 mo	9	6.0	1.26	9	6			9	9	8	8	6	95				8	6	5	5	4
1 yr	6	6.1	1.00	6	5			6	6	6	6	5	100						6		
SAN FRANCISCO																					
5 min	39	4.7	1.62	40	38		38	40					67	27	20	14	9	6	5	4	2
1 hr	25	4.8	1.53	38	22		38	22					68	20	18	13	8	6	5	4	2
8 hr	17	4.9	1.46	18	14		18	14					68		13	11	8	6	5	4	3
1 day	14	5.0	1.41	14	10		14	10					69			9	7	6	5	4	3
1 mo	7	5.1	1.25	7	6		6	7					67				6	6	5	5	4
1 yr	5	5.3	1.00	5	5			5					50						5		
WASHINGTON																					
5 min	87	3.4	2.10	59	29	30	44	29	49	47	37	59	71			27	8	5	4	3	1
1 hr	44	3.6	1.93	41	25	25	41	28	32	38	32	27	71	35	27	17	8	5	4	3	2
8 hr	25	3.7	1.78	34	17	19	34	18	17	22	23	21	72		22	15	8	5	4	3	2
1 day	18	3.8	1.70	23	11	14	23	13	11	15	15	14	73			13	8	5	4	3	2
1 mo	7	4.2	1.41	10	5	7	10	6	6	5	7	7	76				7	5	4	3	2
1 yr	4	4.4	1.00	7	3		7	6	4	3	5	3	86						4		

[a]Standard geometric deviation.

Table 5. HYDROCARBON CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
CHICAGO																					
5 min	20	2.3	1.62	20	14	17	19	20	17	14	18	17	78	15	10	7	4	3	3	2	2
1 hr	12	2.4	1.53	13	8	10	12	8	10	11	13	12	78	12	9	6	4	3	3	2	2
8 hr	8	2.5	1.46	8	6	8	8	6	6	7	7	7	80		7	6	4	3	3	3	2
1 day	7	2.5	1.41	5	5	5	5	5	5	5	5	5	81			5	4	3	3	3	2
1 mo	4	2.6	1.25	4	3	4	4	3	3	3	3	3	88				4	3	3	3	2
1 yr	3	2.6	1.00	3	2	3	3	3	2	2	3	2	100						3		
CINCINNATI																					
5 min	32	2.2	1.84	25	12	15	25	20	16	12	18	18	74	17	13	8	4	3	3	2	2
1 hr	18	2.3	1.72	17	9	11	17	16	13	9	12	14	74	15	12	8	4	3	3	2	2
8 hr	11	2.3	1.61	11	6	7	11	11	9	6	8	8	75		11	7	4	3	3	2	2
1 day	9	2.4	1.54	10	4	6	10	8	6	4	5	5	75			6	4	3	3	2	2
1 mo	4	2.5	1.33	4	2	3	4	3	3	3	2	3	80				4	3	3	3	2
1 yr	3	2.6	1.00	3	2		3	3	2	2	2	2	86						3		
DENVER																					
5 min	32	2.2	1.84	19	18				18	19	18	18	79	18	13	8	4	3	2	2	2
1 hr	18	2.3	1.72	17	13				13	15	13	17	80	16	12	7	4	3	2	2	2
8 hr	11	2.3	1.61	10	6				6	9	10	9	81		9	6	4	3	2	2	2
1 day	9	2.4	1.54	6	5				5	6	5	6	83			5	4	3	2	2	2
1 mo	4	2.5	1.33	4	3				3	3	3	4	90				3	3	2	2	2
1 yr	3	2.6	1.00	2	2				2	2	2	2	100						2		
LOS ANGELES																					
5 min	68	4.3	1.87	90	90		90						85	54	30	20	10	6	4	2	0
1 hr	38	4.5	1.74	30	30		30						85	28	25	19	10	6	4	2	0
8 hr	23	4.7	1.63	21	21		21						86		19	15	10	6	4	2	0
1 day	18	4.7	1.56	17	17		17						87			13	9	6	4	2	0
1 mo	8	5.0	1.34	9	9		9						100				7	5	3	2	1
1 yr	5	5.2	1.00	4	4		4						100						3		

[a]Standard geometric deviation.

Table 5 (Continued). HYDROCARBON CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
PHILADELPHIA																					
5 min	20	2.3	1.62	17	10	12	15	17	10	14	14	13	70	12	9	6	4	3	2	2	1
1 hr	12	2.4	1.53	13	9	9	12	11	9	11	13	11	71	11	9	6	4	3	2	2	1
8 hr	8	2.5	1.46	8	7	7	7	8	7	8	7	8	72		7	5	3	3	2	2	2
1 day	7	2.5	1.41	6	4	5	6	6	5	5	6	4	73			5	3	3	2	2	2
1 mo	4	2.6	1.25	3	2	3	3	2	2	2	2	2	75				3	3	2	2	2
1 yr	3	2.6	1.00	2	2		2	2	2	2	2	2	86						2		
ST. LOUIS																					
5 min	28	2.2	1.77	20	11			20	15	14	11	17	70	16	12	8	5	3	3	2	2
1 hr	16	2.3	1.66	16	11			13	13	12	11	16	70	15	11	8	5	3	3	2	2
8 hr	10	2.4	1.56	13	8			8	10	9	10	13	71		11	8	5	3	3	3	2
1 day	8	2.4	1.50	9	6			6	7	7	8	9	72			7	4	3	3	3	2
1 mo	4	2.5	1.30	4	3			4	3	3	4	4	77				4	4	3	3	2
1 yr	3	2.6	1.00	3	2			3	2	3	3	3	100						3		
SAN FRANCISCO																					
5 min	24	2.3	1.70	17	16	17	17	16					79	14	11	7	4	3	2	2	1
1 hr	14	2.4	1.60	14	12	14	12	12					79	12	10	7	4	3	2	2	1
8 hr	9	2.4	1.51	9	8	9	8	9					80		9	6	4	3	2	2	1
1 day	7	2.4	1.46	8	6	8	6	7					81			6	4	3	3	2	1
1 mo	4	2.5	1.28	4	4	4	4	4					86				3	3	2	2	2
1 yr	3	2.6	1.00	3	2	2	3	3					100						2		
WASHINGTON																					
5 min	28	2.2	1.77	20	12	15	20	17	12	14	15	18	77	15	12	7	3	3	2	2	1
1 hr	16	2.3	1.66	17	9	12	17	14	9	12	15	13	77	14	11	7	3	3	2	2	1
8 hr	10	2.4	1.56	13	7	8	13	10	7	8	11	8	78		9	6	3	3	2	2	2
1 day	8	2.4	1.50	8	4	7	8	7	4	6	5	5	79			5	3	3	2	2	2
1 mo	4	2.5	1.30	3	2	3	3	3	3	2	3	3	83				3	3	2	2	2
1 yr	3	2.6	1.00	3	2		2	3	2	2	2	2	86						2		

[a]Standard geometric deviation.

Table 6. NITRIC OXIDE CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
CHICAGO																					
5 min	1.45	0.077	1.94	0.97	0.63	0.66	0.63	0.97	0.67	0.74	0.69	0.66	79	0.67	0.52	0.33	0.18	0.11	0.08	0.05	0.02
1 hr	0.77	0.081	1.80	0.91	0.60	0.61	0.60	0.91	0.62	0.64	0.63	0.61	79	0.64	0.50	0.32	0.18	0.11	0.08	0.05	0.02
8 hr	0.46	0.084	1.68	0.49	0.34	0.41	0.39	0.49	0.34	0.42	0.41	0.40	83		0.40	0.27	0.17	0.11	0.08	0.06	0.03
1 day	0.35	0.086	1.61	0.36	0.21	0.36	0.35	0.35	0.28	0.34	0.26	0.21	86			0.23	0.15	0.11	0.09	0.07	0.04
1 mo	0.15	0.092	1.36	0.17	0.11	0.17	0.15	0.16	0.13	0.14	0.15	0.11	94				0.13	0.11	0.08	0.07	0.06
1 yr	0.10	0.096	1.00	0.10	0.07	0.10	0.10	0.10	0.10	0.10	0.08	0.07	100						0.10		
CINCINNATI																					
5 min	3.83	0.014	3.59	1.46	0.54	0.60	0.54	0.68	0.63	1.18	1.46	1.26	70	1.08	0.57	0.29	0.09	0.03	0.02	0.01	0.00
1 hr	1.25	0.017	3.10	1.38	0.50	0.58	0.50	0.65	0.62	1.00	1.38	1.02	71	0.98	0.55	0.29	0.09	0.03	0.02	0.01	0.00
8 hr	0.50	0.019	2.70	0.86	0.22	0.38	0.22	0.34	0.40	0.46	0.86	0.58	74		0.40	0.24	0.08	0.04	0.02	0.01	0.01
1 day	0.31	0.021	2.49	0.37	0.15	0.29	0.15	0.2.	0.31	0.37	0.36	0.34	77			0.19	0.08	0.04	0.03	0.02	0.01
1 mo	0.07	0.027	1.81	0.10	0.06	0.06	0.06	0.10	0.07	0.07	0.06	0.08	80				0.06	0.04	0.03	0.02	0.02
1 yr	0.03	0.032	1.00	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03		86						0.03		
DENVER																					
5 min	1.84	0.023	2.72	0.68	0.46				0.46	0.59	0.48	0.68	68	0.55	0.42	0.23	0.09	0.04	0.02	0.01	0.00
1 hr	0.74	0.025	2.43	0.61	0.36				0.40	0.54	0.36	0.61	68	0.52	0.39	0.22	0.09	0.04	0.02	0.01	0.00
8 hr	0.35	0.028	2.18	0.33	0.16				0.16	0.30	0.19	0.33	72		0.24	0.17	0.08	0.04	0.02	0.02	0.01
1 day	0.24	0.029	2.04	0.23	0.11				0.14	0.23	0.11	0.21	74			0.13	0.08	0.04	0.03	0.02	0.01
1 mo	0.07	0.034	1.59	0.08	0.05				0.05	0.08	0.07	0.07	79				0.07	0.05	0.03	0.02	0.01
1 yr	0.04	0.037	1.00	0.04	0.03				0.03	0.04	0.04	0.04	100						0.04		
LOS ANGELES																					
5 min	3.84	0.045	2.75	2.11	0.97	2.11	0.97	1.32					72	1.23	0.85	0.54	0.23	0.08	0.03	0.01	0.00
1 hr	1.54	0.050	2.45	1.42	0.79	1.42	0.79	1.24					72	1.12	0.80	0.53	0.23	0.08	0.03	0.01	0.00
8 hr	0.72	0.055	2.20	0.60	0.49	0.60	0.49	0.60					78		0.55	0.41	0.21	0.09	0.04	0.02	0.01
1 day	0.49	0.058	2.06	0.46	0.38	0.46	0.38	0.44					81			0.36	0.19	0.10	0.05	0.03	0.01
1 mo	0.15	0.067	1.60	0.25	0.18	0.25	0.18	0.19					92				0.16	0.09	0.06	0.03	0.02
1 yr	0.08	0.075	1.00	0.08	0.07	0.08	0.08	0.07					100						0.07		

[a]Standard geometric deviation.

Table 6 (Continued). NITRIC OXIDE CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
PHILADELPHIA																					
5 min	6.54	0.023	3.61	1.98	1.03	1.58	1.72	1.35	1.03	1.98	1.74	1.68	75	1.60	0.95	0.37	0.12	0.05	0.03	0.01	0.00
1 hr	2.12	0.028	3.12	1.87	0.89	1.57	1.51	1.15	0.89	1.87	1.49	1.44	76	1.49	0.93	0.36	0.12	0.05	0.03	0.01	0.00
8 hr	0.84	0.032	2.71	1.00	0.52	0.93	0.91	0.52	0.53	1.00	0.72	0.87	80		0.72	0.31	0.11	0.06	0.03	0.02	0.01
1 day	0.52	0.035	2.50	0.58	0.25	0.46	0.58	0.25	0.31	0.48	0.34	0.37	82			0.25	0.10	0.06	0.04	0.02	0.01
1 mo	0.12	0.044	1.81	0.13	0.07	0.08	0.08	0.09	0.07	0.13	0.10	0.12	87				0.09	0.06	0.05	0.03	0.02
1 yr	0.05	0.053	1.00	0.06	0.04	0.04	0.05	0.04	0.04	0.06	0.06	0.06	100						0.04		
ST. LOUIS																					
5 min	1.27	0.024	2.46	0.84	0.44			0.84	0.52	0.61	0.45	0.44	76	0.51	0.33	0.19	0.08	0.04	0.02	0.01	0.00
1 hr	0.55	0.026	2.22	0.75	0.37			0.75	0.37	0.57	0.41	0.41	76	0.41	0.31	0.18	0.08	0.04	0.02	0.01	0.00
8 hr	0.28	0.028	2.01	0.26	0.17			0.22	0.17	0.26	0.23	0.18	81		0.22	0.14	0.07	0.04	0.02	0.01	0.01
1 day	0.20	0.030	1.90	0.25	0.12			0.14	0.12	0.25	0.17	0.13	84			0.10	0.07	0.04	0.03	0.02	0.01
1 mo	0.07	0.033	1.52	0.07	0.05			0.05	0.06	0.05	0.07	0.05	87				0.05	0.04	0.03	0.03	0.02
1 yr	0.04	0.036	1.00	0.04	0.03			0.03	0.03	0.03	0.04	0.03	100						0.03		
SAN FRANCISCO																					
5 min	2.23	0.057	2.30	1.64	0.50	0.50	1.64	0.81					72	1.25	0.64	0.43	0.18	0.09	0.05	0.03	0.01
1 hr	1.03	0.061	2.09	1.30	0.42	0.42	1.30	0.63					72	0.87	0.60	0.42	0.18	0.09	0.05	0.03	0.01
8 hr	0.54	0.065	1.91	0.52	0.26	0.26	0.52	0.41					77		0.43	0.31	0.18	0.09	0.06	0.03	0.01
1 day	0.39	0.067	1.81	0.32	0.15	0.15	0.32	0.23					77			0.22	0.15	0.10	0.07	0.05	0.02
1 mo	0.14	0.075	1.47	0.13	0.06	0.06	0.11	0.13					83				0.11	0.09	0.08	0.06	0.05
1 yr	0.08	0.081	1.00	0.09	0.09		0.09	0.09					67						0.09		
WASHINGTON																					
5 min	4.64	0.013	3.78	1.26	0.68	0.68	0.73	1.03	0.74	1.15	1.26	0.89	79			0.42	0.10	0.03	0.01	0.01	0.00
1 hr	1.46	0.016	3.25	1.14	0.62	0.65	0.68	0.88	0.62	1.02	1.14	0.69	80	0.88	0.62	0.33	0.09	0.03	0.01	0.01	0.00
8 hr	0.56	0.019	2.81	0.55	0.39	0.39	0.51	0.54	0.39	0.55	0.55	0.43	84		0.48	0.27	0.09	0.04	0.02	0.01	0.00
1 day	0.34	0.021	2.59	0.41	0.21	0.22	0.26	0.29	0.21	0.41	0.36	0.31	86			0.20	0.08	0.04	0.02	0.01	0.01
1 mo	0.07	0.027	1.85	0.10	0.06	0.07	0.08	0.07	0.06	0.09	0.08	0.10	93				0.07	0.04	0.03	0.02	0.01
1 yr	0.03	0.033	1.00	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.04	0.04	100						0.03		

[a]Standard geometric deviation.

Table 7. NITROGEN DIOXIDE CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
CHICAGO																					
5 min	0.45	0.037	1.76	0.79	0.21	0.26	0.23	0.79	0.21	0.35	0.29	0.29	79	0.28	0.18	0.13	0.07	0.05	0.04	0.03	0.02
1 hr	0.26	0.039	1.65	0.47	0.18	0.22	0.21	0.47	0.18	0.31	0.25	0.18	80	0.25	0.18	0.12	0.07	0.05	0.04	0.03	0.02
8 hr	0.17	0.040	1.55	0.22	0.12	0.16	0.17	0.22	0.15	0.20	0.15	0.12	84		0.16	0.12	0.07	0.05	0.04	0.04	0.03
1 day	0.13	0.040	1.49	0.15	0.09	0.12	0.13	0.15	0.09	0.15	0.11	0.10	87			0.10	0.07	0.05	0.04	0.04	0.03
1 mo	0.07	0.042	1.30	0.08	0.05	0.06	0.06	0.07	0.05	0.08	0.07	0.06	93				0.06	0.05	0.04	0.04	0.03
1 yr	0.04	0.044	1.00	0.06	0.04	0.04	0.04	0.05	0.04	0.06	0.05	0.05	100						0.04		
CINCINNATI																					
5 min	0.38	0.030	1.79	1.19	0.21	0.26	0.30	1.00	0.21	0.30	0.70	1.19	79	0.26	0.16	0.09	0.05	0.04	0.03	0.02	0.02
1 hr	0.22	0.031	1.67	0.56	0.17	0.23	0.25	0.34	0.17	0.24	0.24	0.56	79	0.24	0.15	0.09	0.05	0.04	0.03	0.02	0.02
8 hr	0.14	0.032	1.57	0.16	0.10	0.12	0.14	0.14	0.10	0.13	0.13	0.16	83		0.12	0.08	0.05	0.04	0.03	0.02	0.02
1 day	0.11	0.032	1.51	0.10	0.07	0.07	0.09	0.10	0.08	0.09	0.07	0.10	86			0.07	0.05	0.04	0.03	0.03	0.02
1 mo	0.05	0.034	1.31	0.05	0.04	0.04	0.04	0.05	0.04	0.05	0.04	0.05	94				0.04	0.04	0.03	0.03	0.02
1 yr	0.03	0.035	1.00	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	100						0.03		
DENVER																					
5 min	0.47	0.029	1.89	0.38	0.30				0.31	0.30	0.37	0.38	71	0.31	0.18	0.11	0.06	0.04	0.03	0.03	0.02
1 hr	0.26	0.030	1.76	0.33	0.25				0.28	0.27	0.33	0.25	72	0.27	0.17	0.10	0.06	0.04	0.03	0.03	0.02
8 hr	0.16	0.031	1.64	0.18	0.12				0.14	0.18	0.17	0.12	76		0.13	0.09	0.05	0.04	0.03	0.03	0.02
1 day	0.12	0.032	1.57	0.12	0.08				0.09	0.09	0.08	0.12	79			0.08	0.05	0.04	0.03	0.03	0.02
1 mo	0.05	0.033	1.34	0.05	0.04				0.04	0.04	0.04	0.05	81				0.04	0.04	0.03	0.03	0.03
1 yr	0.03	0.035	1.00	0.04	0.03				0.04	0.03	0.04	0.04	100						0.04		
LOS ANGELES																					
5 min	1.48	0.038	2.30	1.27	0.57		0.57	1.27					63	0.66	0.44	0.25	0.12	0.06	0.04	0.03	0.01
1 hr	0.69	0.041	2.09	0.68	0.52		0.52	0.68					63	0.55	0.40	0.24	0.11	0.06	0.04	0.03	0.01
8 hr	0.36	0.044	1.91	0.37	0.27		0.37	0.27					67		0.27	0.23	0.11	0.06	0.05	0.03	0.02
1 day	0.26	0.045	1.81	0.26	0.20		0.20	0.26					71			0.18	0.10	0.07	0.05	0.04	0.02
1 mo	0.09	0.050	1.47	0.10	0.07		0.10	0.07					79				0.09	0.05	0.04	0.04	0.03
1 yr	0.05	0.054	1.00	0.06	0.05		0.06	0.05					100						0.05		

[a]Standard geometric deviation.

Table 7 (Continued). NITROGEN DIOXIDE CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
PHILADELPHIA																					
5 min	0.52	0.028	1.94	0.44	0.22	0.24	0.36	0.37	0.24	0.29	0.44	0.22	79	0.25	0.18	0.11	0.07	0.04	0.03	0.03	0.02
1 hr	0.28	0.030	1.80	0.32	0.20	0.22	0.32	0.26	0.20	0.23	0.23	0.20	79	0.23	0.18	0.11	0.07	0.04	0.04	0.03	0.02
8 hr	0.17	0.031	1.67	0.19	0.10	0.14	0.19	0.14	0.10	0.15	0.13	0.12	84		0.13	0.10	0.06	0.05	0.04	0.03	0.02
1 day	0.13	0.031	1.60	0.14	0.07	0.10	0.14	0.10	0.07	0.10	0.10	0.09	86			0.08	0.06	0.05	0.04	0.03	0.02
1 mo	0.06	0.033	1.36	0.06	0.04	0.05	0.06	0.05	0.04	0.05	0.05	0.05	90				0.05	0.04	0.04	0.03	0.03
1 yr	0.04	0.035	1.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	100						0.04		
ST. LOUIS																					
5 min	0.36	0.021	1.90	0.31	0.17			0.31	0.28	0.21	0.17	0.20	81	0.21	0.13	0.08	0.05	0.03	0.03	0.02	0.01
1 hr	0.20	0.022	1.77	0.22	0.13			0.22	0.13	0.20	0.16	0.18	81	0.20	0.13	0.08	0.05	0.03	0.03	0.02	0.01
8 hr	0.12	0.023	1.65	0.14	0.08			0.14	0.08	0.14	0.09	0.09	87		0.11	0.07	0.05	0.03	0.03	0.02	0.01
1 day	0.09	0.024	1.58	0.12	0.05			0.12	0.05	0.10	0.06	0.05	89			0.07	0.04	0.03	0.03	0.02	0.01
1 mo	0.04	0.025	1.35	0.04	0.03			0.04	0.03	0.04	0.03	0.04	92				0.04	0.03	0.03	0.02	0.02
1 yr	0.03	0.026	1.00	0.04	0.02			0.04	0.03	0.03	0.03	0.02	100						0.03		
SAN FRANCISCO																					
5 min	0.87	0.041	2.00	0.52	0.38	0.50	0.38	0.52					70	0.43	0.31	0.18	0.08	0.06	0.04	0.03	0.01
1 hr	0.46	0.044	1.85	0.41	0.27	0.27	0.33	0.41					70	0.38	0.29	0.18	0.08	0.06	0.04	0.03	0.01
8 hr	0.27	0.046	1.71	0.31	0.16	0.16	0.23	0.31					75		0.23	0.16	0.08	0.06	0.04	0.03	0.01
1 day	0.20	0.047	1.64	0.18	0.10	0.10	0.13	0.18					75			0.12	0.07	0.06	0.04	0.03	0.02
1 mo	0.09	0.050	1.38	0.08	0.04	0.04	0.06	0.08					83				0.07	0.05	0.05	0.04	0.02
1 yr	0.05	0.053	1.00	0.06	0.03	0.03	0.05	0.06					100						0.03		
WASHINGTON																					
5 min	0.38	0.030	1.79	0.37	0.19	0.37	0.24	0.24	0.25	0.19	0.24	0.26	79	0.22	0.16	0.10	0.06	0.04	0.03	0.03	0.02
1 hr	0.22	0.031	1.67	0.30	0.18	0.30	0.22	0.23	0.23	0.18	0.21	0.24	79	0.21	0.15	0.10	0.06	0.04	0.03	0.03	0.02
8 hr	0.14	0.032	1.57	0.14	0.09	0.10	0.11	0.14	0.10	0.09	0.14	0.13	84		0.11	0.09	0.06	0.04	0.03	0.03	0.02
1 day	0.11	0.032	1.51	0.10	0.07	0.07	0.09	0.10	0.07	0.07	0.09	0.08	86			0.08	0.06	0.04	0.04	0.03	0.02
1 mo	0.05	0.034	1.31	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	95				0.05	0.04	0.04	0.03	0.03
1 yr	0.03	0.035	1.00	0.05	0.03	0.03	0.03	0.04	0.03	0.03	0.04	0.05	100						0.03		

[a]Standard geometric deviation.

Table 8. NITROGEN OXIDES CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
CHICAGO																					
5 min	1.43	0.128	1.73	1.12	0.72	0.78	0.72	1.12	0.74	0.86	0.81	0.78	73	0.79	0.62	0.40	0.23	0.16	0.13	0.09	0.06
1 hr	0.85	0.132	1.62	1.06	0.68	0.69	0.68	1.06	0.68	0.75	0.74	0.73	74	0.75	0.59	0.39	0.23	0.17	0.13	0.09	0.06
8 hr	0.55	0.136	1.53	0.62	0.41	0.54	0.51	0.62	0.41	0.52	0.46	0.49	78		0.49	0.34	0.22	0.16	0.13	0.10	0.07
1 day	0.44	0.138	1.48	0.50	0.30	0.42	0.43	0.50	0.34	0.44	0.31	0.30	81			0.30	0.20	0.16	0.13	0.11	0.09
1 mo	0.22	0.144	1.29	0.22	0.15	0.21	0.18	0.22	0.17	0.19	0.19	0.15	89				0.17	0.15	0.13	0.12	0.10
1 yr	0.15	0.149	1.00	0.16	0.12	0.14	0.14	0.15	0.14	0.16	0.13	0.12	100						0.14		
CINCINNATI																					
5 min	2.83	0.041	2.62	1.51	0.49	0.69	0.49	1.02	0.74	1.35	1.51	1.26	65	1.20	0.66	0.35	0.13	0.07	0.05	0.04	0.02
1 hr	1.18	0.045	2.35	1.42	0.45	0.68	0.45	0.73	0.73	1.22	1.42	0.95	66	1.03	0.63	0.34	0.13	0.07	0.05	0.04	0.02
8 hr	0.57	0.049	2.12	0.90	0.29	0.50	0.29	0.51	0.51	0.67	0.90	0.46	69		0.49	0.29	0.12	0.07	0.05	0.04	0.03
1 day	0.39	0.051	1.99	0.46	0.21	0.37	0.21	0.39	0.39	0.46	0.39	0.32	72			0.23	0.12	0.07	0.06	0.04	0.03
1 mo	0.12	0.059	1.56	0.12	0.09	0.09	0.10	0.12	0.12	0.11	0.10	0.11	74				0.10	0.07	0.06	0.05	0.05
1 yr	0.06	0.065	1.00	0.08	0.06	0.06	0.06	0.07	0.07	0.08	0.06		86						0.06		
DENVER																					
5 min	1.78	0.052	2.24	0.80	0.61				0.61	0.68	0.62	0.80	61	0.64	0.53	0.31	0.14	0.08	0.05	0.04	0.02
1 hr	0.84	0.055	2.04	0.72	0.56				0.56	0.62	0.59	0.72	62	0.60	0.50	0.30	0.14	0.08	0.06	0.04	0.02
8 hr	0.45	0.059	1.87	0.44	0.27				0.27	0.36	0.33	0.44	65		0.33	0.24	0.13	0.08	0.06	0.05	0.03
1 day	0.33	0.060	1.78	0.31	0.17				0.22	0.28	0.17	0.31	68			0.20	0.13	0.08	0.06	0.05	0.04
1 mo	0.12	0.066	1.45	0.13	0.09				0.09	0.13	0.11	0.13	63				0.12	0.09	0.06	0.05	0.04
1 yr	0.07	0.071	1.00	0.07	0.06				0.06	0.07			50						0.06		
LOS ANGELES																					
5 min	3.69	0.088	2.34	1.49	1.12		1.12	1.49					61	1.28	0.97	0.67	0.31	0.14	0.08	0.05	0.02
1 hr	1.68	0.095	2.12	1.39	1.07		1.07	1.39					61	1.09	0.97	0.67	0.31	0.14	0.08	0.05	0.02
8 hr	0.88	0.101	1.94	0.78	0.71		0.71	0.78					64		0.71	0.53	0.29	0.14	0.09	0.05	0.03
1 day	0.63	0.105	1.84	0.55	0.54		0.54	0.55					68			0.48	0.26	0.15	0.09	0.06	0.04
1 mo	0.22	0.116	1.48	0.28	0.23		0.28	0.23					79				0.23	0.11	0.09	0.08	0.05
1 yr	0.13	0.126	1.00	0.13	0.12		0.13	0.12					100						0.12		

[a]Standard geometric deviation.

Table 8 (Continued). NITROGEN OXIDES CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
PHILADELPHIA																					
5 min	4.80	0.056	2.75	2.16	1.14	1.81	1.93	1.50	1.14	2.16	1.87	1.82	70	1.81	1.04	0.42	0.17	0.10	0.07	0.05	0.03
1 hr	1.92	0.063	2.45	2.02	0.97	1.79	1.69	1.27	0.97	2.02	1.62	1.61	71	1.69	1.00	0.41	0.17	0.10	0.07	0.05	0.03
8 hr	0.90	0.069	2.20	1.11	0.45	1.06	1.06	0.45	0.60	1.11	0.79	0.98	75		0.80	0.36	0.16	0.10	0.07	0.05	0.03
1 day	0.61	0.072	2.06	0.70	0.28	0.56	0.70	0.28	0.38	0.58	0.42	0.44	76			0.29	0.15	0.10	0.08	0.06	0.04
1 mo	0.18	0.084	1.60	0.18	0.10	0.13	0.12	0.10	0.10	0.18	0.15	0.15	81				0.12	0.09	0.08	0.07	0.06
1 yr	0.09	0.094	1.00	0.10	0.08	0.08		0.08	0.08	0.10	0.10	0.10	83						0.08		
ST. LOUIS																					
5 min	1.18	0.047	2.08	1.02	0.52			1.02	0.59	0.72	0.52	0.52	73	0.61	0.39	0.24	0.12	0.07	0.05	0.03	0.02
1 hr	0.60	0.050	1.91	0.92	0.44			0.92	0.44	0.66	0.48	0.46	73	0.55	0.37	0.23	0.12	0.07	0.05	0.03	0.02
8 hr	0.34	0.052	1.77	0.39	0.21			0.26	0.21	0.39	0.28	0.21	78		0.27	0.18	0.11	0.07	0.06	0.04	0.02
1 day	0.25	0.054	1.69	0.35	0.14			0.25	0.14	0.35	0.22	0.15	82			0.15	0.10	0.07	0.06	0.04	0.03
1 mo	0.10	0.058	1.40	0.09	0.07			0.08	0.07	0.09	0.08	0.08	85				0.07	0.07	0.06	0.05	0.04
1 yr	0.06	0.062	1.00	0.07	0.05			0.07	0.05	0.07	0.06	0.06	100						0.06		
SAN FRANCISCO																					
5 min	1.96	0.105	1.94	1.69	0.58	0.58	1.69	0.91					65	1.31	0.72	0.52	0.26	0.15	0.10	0.06	0.03
1 hr	1.05	0.110	1.80	1.35	0.49	0.49	1.35	0.76					65	0.92	0.68	0.51	0.26	0.15	0.10	0.06	0.03
8 hr	0.62	0.115	1.68	0.56	0.31	0.31	0.56	0.52					69		0.49	0.41	0.25	0.15	0.11	0.07	0.03
1 day	0.48	0.117	1.61	0.36	0.23	0.23	0.36	0.31					68			0.30	0.22	0.15	0.12	0.09	0.06
1 mo	0.21	0.125	1.36	0.20	0.10	0.10	0.16	0.20					75				0.16	0.14	0.13	0.10	0.07
1 yr	0.13	0.131	1.00	0.14	0.14		0.14	0.14					67						0.14		
WASHINGTON																					
5 min	3.44	0.039	2.77	1.47	0.79	0.79	0.86	1.16	0.84	0.85	1.47	1.00	71	1.00	0.70	0.38	0.14	0.07	0.05	0.03	0.02
1 hr	1.37	0.044	2.46	1.30	0.68	0.74	0.76	1.00	0.71	0.68	1.30	0.78	71	0.97	0.71	0.38	0.14	0.07	0.05	0.04	0.02
8 hr	0.64	0.048	2.21	0.69	0.41	0.43	0.58	0.69	0.45	0.41	0.56	0.49	75		0.54	0.31	0.13	0.07	0.05	0.04	0.03
1 day	0.43	0.051	2.07	0.45	0.27	0.27	0.35	0.38	0.27	0.30	0.45	0.38	78			0.25	0.12	0.08	0.06	0.05	0.03
1 mo	0.13	0.059	1.60	0.14	0.10	0.11	0.13	0.12	0.10	0.12	0.11	0.14	86				0.10	0.08	0.06	0.05	0.04
1 yr	0.07	0.066	1.00	0.09	0.06	0.06	0.07	0.07	0.07	0.07	0.08	0.09	100						0.07		

[a]Standard geometric deviation.

Table 9. OXIDANT CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962[b]	1963[b]	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
CHICAGO																					
5 min	0.36	0.021	1.90	0.47	0.17	0.25	0.24	0.17	0.19	0.23	0.21	0.47	60	0.19	0.14	0.09	0.05	0.03	0.02	0.01	0.00
1 hr	0.20	0.022	1.77	0.23	0.12	0.23	0.21	0.12	0.13	0.19	0.16	0.18	61	0.16	0.13	0.09	0.05	0.03	0.02	0.01	0.00
8 hr	0.12	0.023	1.65	0.14	0.08	0.09	0.08	0.09	0.10	0.12	0.12	0.14	66		0.12	0.08	0.05	0.03	0.02	0.02	0.00
1 day	0.09	0.024	1.58	0.11	0.03	0.07	0.03	0.08	0.08	0.08	0.08	0.11	68			0.07	0.05	0.03	0.03	0.02	0.01
1 mo	0.04	0.025	1.35	0.05	0.01	0.01	0.01	0.05	0.04	0.03	0.04	0.04	75				0.04	0.03	0.03	0.02	0.01
1 yr	0.03	0.026	1.00	0.03	0.02			0.03	0.03	0.02	0.03	0.02	100						0.02		
CINCINNATI																					
5 min	0.46	0.021	2.03	0.32	0.13	0.20	0.24	0.32	0.19	0.13	0.25	0.19	59	0.20	0.15	0.11	0.06	0.03	0.02	0.02	0.01
1 hr	0.24	0.022	1.87	0.26	0.12	0.14	0.20	0.26	0.17	0.12	0.20	0.14	59	0.19	0.15	0.10	0.06	0.03	0.02	0.02	0.01
8 hr	0.14	0.023	1.73	0.16	0.08	0.10	0.14	0.16	0.12	0.08	0.13	0.10	63		0.13	0.09	0.05	0.03	0.02	0.02	0.01
1 day	0.10	0.023	1.66	0.10	0.05	0.06	0.09	0.09	0.10	0.06	0.09	0.05	65			0.07	0.05	0.03	0.03	0.02	0.01
1 mo	0.04	0.025	1.39	0.06	0.03	0.03	0.04	0.06	0.04	0.04	0.05	0.03	60				0.04	0.04	0.03	0.02	0.02
1 yr	0.03	0.026	1.00	0.03	0.01	0.01	0.02	0.03	0.03		0.03		60						0.03		
DENVER																					
5 min	0.47	0.029	1.89	0.43	0.26					0.30	0.26	0.43	54	0.25	0.19	0.11	0.06	0.04	0.02	0.02	0.01
1 hr	0.26	0.030	1.76	0.26	0.21					0.23	0.21	0.26	55	0.23	0.17	0.11	0.06	0.04	0.02	0.02	0.01
8 hr	0.16	0.031	1.64	0.13	0.12					0.13	0.12	0.13	59		0.12	0.09	0.06	0.03	0.03	0.02	0.01
1 day	0.12	0.032	1.57	0.09	0.07					0.07	0.09	0.08	62			0.07	0.05	0.04	0.03	0.02	0.01
1 mo	0.05	0.033	1.34	0.04	0.03					0.04	0.03	0.04	53				0.04	0.03	0.03	0.02	0.01
1 yr	0.03	0.035	1.00	0.03	0.03					0.03			33						0.03		
LOS ANGELES																					
5 min	1.47	0.024	2.56	1.40	0.53	0.53	1.40	0.88					47	0.52	0.38	0.23	0.12	0.04	0.02	0.01	0.00
1 hr	0.62	0.026	2.30	0.49	0.41	0.49	0.49	0.41					69	0.47	0.34	0.21	0.10	0.04	0.02	0.01	0.00
8 hr	0.31	0.028	2.08	0.31	0.25	0.31	0.25	0.26					53		0.25	0.19	0.12	0.05	0.03	0.02	0.01
1 day	0.21	0.029	1.96	0.16	0.13	0.16	0.14	0.13					66			0.12	0.07	0.06	0.04	0.03	0.01
1 mo	0.07	0.033	1.55	0.07	0.06	0.06	0.06	0.07					28				0.06	0.06	0.06	0.04	0.02
1 yr	0.04	0.037	1.00										0						0.06		

[a]Standard geometric deviation.

[b]Sulfur dioxide interference caused low concentration readings for oxidant in 1962 and 1963. This fact shows especially for maximum concentrations for averaging times of 1 month and 1 year. Data for these 2 years were not used for the frequency distributions above, except in Los Angeles and San Francisco, where the interference was much less serious. Interference was controlled after 1963.

Table 9(Continued). OXIDANT CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962[b]	1963[b]	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
PHILADELPHIA																					
5 min	0.93	0.018	2.45	0.60	0.12	0.12	0.13	0.25	0.25	0.60	0.29	0.31	72	0.51	0.24	0.13	0.06	0.03	0.02	0.01	0.00
1 hr	0.41	0.020	2.21	0.52	0.10	0.10	0.11	0.21	0.21	0.52	0.17	0.21	72	0.44	0.23	0.13	0.06	0.03	0.02	0.01	0.00
8 hr	0.21	0.021	2.01	0.35	0.08	0.08	0.08	0.14	0.14	0.35	0.13	0.13	78		0.18	0.11	0.05	0.03	0.02	0.02	0.01
1 day	0.15	0.022	1.89	0.18	0.05	0.05	0.05	0.09	0.09	0.18	0.08	0.08	79			0.08	0.05	0.03	0.02	0.02	0.01
1 mo	0.05	0.025	1.51	0.06	0.02	0.02	0.02	0.04	0.04	0.06	0.05	0.03	89				0.04	0.03	0.03	0.02	0.01
1 yr	0.03	0.027	1.00	0.03	0.01	0.01	0.01	0.02	0.03	0.03	0.03		100						0.02		
ST. LOUIS																					
5 min	0.43	0.029	1.84	0.62	0.25				0.62	0.25	0.27	0.37	69	0.32	0.17	0.10	0.06	0.04	0.03	0.02	0.01
1 hr	0.24	0.030	1.72	0.35	0.20				0.35	0.22	0.20	0.23	70	0.23	0.16	0.10	0.06	0.04	0.03	0.02	0.01
8 hr	0.15	0.031	1.61	0.14	0.08				0.12	0.11	0.14	0.08	75		0.12	0.09	0.06	0.04	0.03	0.02	0.01
1 day	0.12	0.032	1.54	0.10	0.05				0.07	0.09	0.10	0.05	79			0.07	0.05	0.04	0.03	0.02	0.01
1 mo	0.05	0.034	1.33	0.06	0.03				0.04	0.06	0.05	0.03	79				0.04	0.04	0.03	0.02	0.02
1 yr	0.03	0.035	1.00	0.04	0.02				0.03	0.04	0.04	0.02	100						0.03		
SAN FRANCISCO																					
5 min	0.54	0.012	2.35	0.42	0.29	0.32	0.29	0.42					65	0.26	0.15	0.07	0.04	0.02	0.02	0.01	0.00
1 hr	0.24	0.013	2.13	0.26	0.17	0.26	0.17	0.17					65	0.25	0.14	0.07	0.04	0.02	0.02	0.01	0.00
8 hr	0.13	0.014	1.94	0.16	0.10	0.16	0.10	0.11					69		0.11	0.06	0.03	0.02	0.02	0.01	0.01
1 day	0.09	0.015	1.84	0.09	0.05	0.09	0.08	0.05					69			0.06	0.03	0.02	0.02	0.01	0.01
1 mo	0.03	0.017	1.49	0.04	0.03	0.03	0.04	0.03					72				0.02	0.02	0.02	0.01	0.01
1 yr	0.02	0.018	1.00	0.02	0.02	0.02	0.02	0.02					100						0.02		
WASHINGTON																					
5 min	0.46	0.021	2.03	0.32	0.17	0.17	0.25	0.19	0.24	0.22	0.32	0.29	75	0.20	0.15	0.11	0.06	0.03	0.02	0.01	0.00
1 hr	0.24	0.022	1.87	0.26	0.13	0.13	0.22	0.18	0.21	0.16	0.26	0.25	76	0.20	0.15	0.11	0.06	0.03	0.02	0.01	0.00
8 hr	0.14	0.023	1.73	0.17	0.10	0.10	0.16	0.11	0.12	0.12	0.17	0.13	80		0.12	0.10	0.06	0.03	0.02	0.02	0.01
1 day	0.10	0.023	1.66	0.11	0.06	0.06	0.08	0.08	0.09	0.10	0.11	0.10	83			0.07	0.05	0.04	0.03	0.02	0.01
1 mo	0.04	0.025	1.39	0.04	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	89				0.04	0.03	0.03	0.02	0.01
1 yr	0.03	0.026	1.00	0.03	0.01	0.01	0.01	0.03	0.03	0.03	0.03	0.03	100						0.03		

[a] Standard geometric deviation.

[b] Sulfur dioxide interference caused low concentration readings for oxidant in 1962 and 1963. This fact shows especially for maximum concentrations for averaging times of 1 month and 1 year. Data for these 2 years were not used for the frequency distributions above, except in Los Angeles and San Francisco, where the interference was much less serious. Interference was controlled after 1963.

Table 10. SULFUR DIOXIDE CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
CHICAGO																					
5 min	3.27	0.104	2.19	1.94	1.11	1.13	1.94	1.62	1.59	1.11	1.62	1.33	83	1.31	1.01	0.67	0.32	0.16	0.08	0.03	0.01
1 hr	1.58	0.112	2.00	1.69	0.86	0.86	1.69	1.12	1.14	0.98	1.11	0.91	83	1.11	0.95	0.64	0.32	0.16	0.08	0.03	0.01
8 hr	0.86	0.118	1.84	1.02	0.45	0.45	0.87	1.02	0.74	0.63	0.80	0.63	84		0.74	0.56	0.31	0.16	0.09	0.04	0.01
1 day	0.63	0.121	1.75	0.79	0.36	0.36	0.71	0.79	0.55	0.48	0.65	0.51	86			0.49	0.30	0.16	0.09	0.05	0.02
1 mo	0.24	0.133	1.44	0.35	0.18	0.18	0.33	0.35	0.27	0.26	0.32	0.26	94				0.27	0.18	0.09	0.06	0.03
1 yr	0.14	0.142	1.00	0.18	0.09	0.10	0.14	0.18	0.13	0.09	0.12	0.12	100						0.12		
CINCINNATI																					
5 min	1.68	0.016	2.87	1.49	0.65	0.84	0.99	0.88	1.15	0.70	0.65	1.49	80	0.68	0.41	0.19	0.06	0.03	0.02	0.01	0.00
1 hr	0.65	0.018	2.54	0.57	0.38	0.46	0.48	0.55	0.57	0.41	0.42	0.38	80	0.53	0.33	0.16	0.06	0.03	0.02	0.01	0.00
8 hr	0.30	0.020	2.27	0.38	0.14	0.14	0.23	0.27	0.38	0.18	0.18	0.18	81		0.22	0.12	0.06	0.03	0.02	0.01	0.00
1 day	0.20	0.022	2.12	0.18	0.08	0.11	0.11	0.14	0.18	0.10	0.13	0.08	82			0.10	0.06	0.04	0.03	0.02	0.01
1 mo	0.06	0.025	1.63	0.06	0.03	0.04	0.06	0.06	0.06	0.05	0.04	0.03	86				0.05	0.03	0.03	0.02	0.01
1 yr	0.03	0.029	1.00	0.04	0.02	0.03	0.03	0.04	0.03	0.03	0.02	0.02	100						0.03		
DENVER																					
5 min	0.47	0.013	2.28	1.81	0.33				0.95	0.96	0.33	1.81	78	0.38	0.18	0.08	0.03	0.02	0.01	0.00	0.00
1 hr	0.22	0.014	2.07	0.36	0.17				0.36	0.26	0.17	0.24	78	0.26	0.13	0.07	0.03	0.02	0.01	0.00	0.00
8 hr	0.12	0.015	1.90	0.14	0.05				0.14	0.10	0.05	0.10	79		0.10	0.05	0.03	0.02	0.01	0.00	0.00
1 day	0.09	0.015	1.80	0.07	0.02				0.06	0.05	0.02	0.07	81			0.04	0.03	0.02	0.01	0.00	0.00
1 mo	0.03	0.017	1.46	0.03	0.01				0.03	0.02	0.01	0.03	83				0.02	0.02	0.01	0.01	0.00
1 yr	0.02	0.018	1.00	0.02	0.01				0.02	0.01		0.01	100						0.01		
LOS ANGELES																					
5 min	0.47	0.013	2.28	0.68	0.24	0.24	0.51	0.68					59	0.38	0.15	0.08	0.04	0.02	0.01	0.01	0.00
1 hr	0.22	0.014	2.07	0.29	0.13	0.13	0.19	0.29					67	0.25	0.13	0.08	0.04	0.02	0.01	0.01	0.00
8 hr	0.12	0.015	1.90	0.13	0.08	0.08	0.09	0.13					71		0.10	0.07	0.04	0.02	0.02	0.01	0.00
1 day	0.09	0.015	1.80	0.10	0.06	0.06	0.07	0.10					71			0.06	0.04	0.02	0.02	0.01	0.00
1 mo	0.03	0.017	1.46	0.03	0.02	0.03	0.03	0.02					64				0.02	0.02	0.02	0.01	0.01
1 yr	0.02	0.018	1.00	0.02	0.02	0.02	0.02						67						0.02		

[a]Standard geometric deviation.

Table 10 (Continued). SULFUR DIOXIDE CONCENTRATION (ppm) AT CAMP SITES, BY AVERAGING TIME AND FREQUENCY, 1962 THROUGH 1968

City and averaging time	Annual maximum	1962 through 1968				Maximum for year							Percent data available	Percent of time concentration is exceeded							
		Geom. mean	SGD[a]	Max	Min	1962	1963	1964	1965	1966	1967	1968		0.01	0.1	1	10	30	50	70	90
PHILADELPHIA																					
5 min	2.67	0.055	2.41	1.25	0.79	1.25	1.05	1.00	1.11	0.79	1.12	1.10	77	0.96	0.72	0.48	0.20	0.09	0.05	0.03	0.01
1 hr	1.19	0.060	2.18	1.03	0.66	1.03	0.85	0.84	0.94	0.66	0.77	0.88	78	0.85	0.67	0.45	0.20	0.09	0.05	0.03	0.01
8 hr	0.61	0.064	1.99	0.71	0.43	0.56	0.58	0.54	0.71	0.43	0.56	0.55	79		0.52	0.37	0.19	0.10	0.06	0.04	0.01
1 day	0.43	0.067	1.88	0.46	0.35	0.35	0.46	0.43	0.35	0.36	0.35	0.36	81			0.31	0.17	0.10	0.07	0.04	0.02
1 mo	0.15	0.075	1.50	0.16	0.12	0.13	0.12	0.15	0.13	0.13	0.13	0.16	88				0.12	0.10	0.08	0.07	0.04
1 yr	0.08	0.081	1.00	0.10	0.06	0.09	0.06	0.09	0.08	0.09	0.10	0.08	100						0.08		
ST. LOUIS																					
5 min	2.32	0.028	2.72	1.42	0.85			1.16	1.42	1.25	0.85	1.33	83	0.94	0.56	0.28	0.10	0.04	0.02	0.01	0.00
1 hr	0.94	0.032	2.43	0.96	0.55			0.73	0.96	0.84	0.55	0.68	83	0.73	0.49	0.25	0.10	0.05	0.02	0.01	0.00
8 hr	0.44	0.034	2.18	0.36	0.23			0.31	0.36	0.33	0.24	0.23	84		0.29	0.18	0.09	0.05	0.03	0.02	0.00
1 day	0.30	0.036	2.05	0.26	0.16			0.26	0.19	0.18	0.21	0.16	86			0.14	0.08	0.05	0.03	0.02	0.01
1 mo	0.09	0.042	1.59	0.08	0.05			0.08	0.06	0.06	0.05	0.06	90				0.06	0.05	0.04	0.03	0.01
1 yr	0.05	0.047	1.00	0.06	0.03			0.06	0.05	0.04	0.03	0.03	100						0.03		
SAN FRANCISCO																					
5 min	0.56	0.005	2.87	0.33	0.16	0.16	0.33	0.26					64	0.18	0.13	0.07	0.03	0.01	0.01	0.00	0.00
1 hr	0.22	0.006	2.54	0.26	0.11	0.11	0.26	0.16					64	0.16	0.11	0.07	0.03	0.01	0.01	0.00	0.00
8 hr	0.10	0.007	2.27	0.10	0.06	0.06	0.07	0.10					65		0.09	0.06	0.03	0.02	0.01	0.00	0.00
1 day	0.07	0.007	2.12	0.08	0.05	0.05	0.05	0.08					65			0.05	0.03	0.02	0.01	0.00	0.00
1 mo	0.02	0.008	1.63	0.03	0.01	0.01	0.02	0.03					75				0.02	0.01	0.01	0.01	0.00
1 yr	0.01	0.010	1.00	0.02	0.01		0.01	0.02					67						0.01		
WASHINGTON																					
5 min	1.14	0.040	2.14	0.87	0.42	0.42	0.56	0.87	0.44	0.47	0.44	0.53	70	0.49	0.35	0.21	0.10	0.06	0.03	0.02	0.00
1 hr	0.56	0.042	1.96	0.62	0.35	0.38	0.48	0.62	0.35	0.45	0.37	0.42	70	0.45	0.34	0.21	0.10	0.06	0.03	0.02	0.00
8 hr	0.31	0.045	1.81	0.35	0.22	0.23	0.35	0.32	0.27	0.34	0.22	0.22	71		0.26	0.18	0.10	0.06	0.04	0.02	0.01
1 day	0.23	0.046	1.72	0.25	0.15	0.18	0.25	0.22	0.20	0.25	0.15	0.18	72			0.16	0.10	0.06	0.04	0.02	0.01
1 mo	0.09	0.050	1.42	0.11	0.07	0.10	0.11	0.09	0.08	0.10	0.07	0.10	76				0.09	0.06	0.04	0.02	0.01
1 yr	0.05	0.053	1.00	0.05	0.04	0.05	0.05	0.04	0.05	0.04		0.04	86						0.04		

[a]Standard geometric deviation.

The next item to consider is the annual maximum 1-hour concentration. There are 8760 hours in a year. If an hourly value were available for every one of these hours, and if one were certain that each of the values were completely accurate, then the maximum observed value could be used as an accurate expression for the maximum 1-hour concentration for that year. Data are not available, however, for 100 percent of the hours, and the accuracy of the 8760th highest value might be questioned, even if all values were available. One alternative is to select a frequency close to the actual maximum, but far enough away to compensate for the possibility of inaccuracy in higher observations. The 0.1-percent frequency has been selected for this purpose. It represents the ninth highest value in the year, if data are available for 100 percent of the hours. *A line drawn through the 0.1- and 30-percentile points (*points on Figure 3) should thus give a good estimate of both the annual maximum 1-hour and the arithmetic mean concentrations.*

If each year had the same meteorology and source-strnegth pattern, then the same frequency distribution could be expected each year. This is not the case, as witnessed by severe air pollution episodes in London and New York, which, fortunately, do not occur every year.[12] This variation from year to year is also shown by the fact that the highest maximum 1-hour concentration observed during 1 of the 7 years shown in Tables 4 through 10 is often about twice as great as the maximum observed in the lowest year for the same city. Since the most polluted year may have several hours of high pollution, it can markedly affect the calculated annual maximum 1-hour concentration. In fact, the annual maximum values calculated in column 2 of Tables 4 through 10 are often about the same as the maximum observed during the 7-year period (column 5). Although the distribution is markedly affected by the high concentrations during the most polluted years, it is these same concentrations that need to be controlled if an air pollution problem is to be alleviated and air quality standards are to be met. *The calculated annual maximum concentration is thus suggested as a good design value to use when determining control strategies and implementation plans.*

Some air quality standards may specify maximum values that are not to be exceeded. In order to treat these data statistically, however, some frequency limit must be assigned to the maxima, whether the frequency be once a year, once a decade, or once a century. A frequency of once a year is suggested here. Although some sets of data depart from lognormality, use of the lognormal distribution is recommended because most aerometric data tend to fit this distribution better than any other.

CALCULATING THE STANDARD GEOMETRIC DEVIATION

The standard geometric deviation is presented graphically on Figure 3,[13] in which it is shown as the 16-percentile concentration (1 standard deviation from the median) divided by the 50-percentile concentration. Actually, the standard geometric deviation can be calculated from any two points on the distribution, as will now be shown.

As mentioned before, the slope of the plotted line is analogous to the standard geometric deviation. The ordinate on Figure 3 is logarithmic. The abscissa, expressed as the number of standard deviations from the median (top axis), is arithmetic. The slope, p, of a line on such a semi-logarithmic plot[12] is

$$p = \frac{\ln c_h - \ln c_i}{z_h - z_i} \tag{15}$$

or

$$p = \frac{\ln (c_h/c_i)}{z_h - z_i} \tag{16}$$

where p = slope,

c_h = the concentration at point h,

c_i = the concentration at point i,

z_h = the number of standard deviations between h and the median, and

z_i = the number of standard deviations between i and the median.

The standard geometric deviation is the antilogarithm of the slope, p.

$$s_g = \exp\left[\frac{\ln(c_h/c_i)}{z_h - z_i}\right] \qquad *(17)$$

Note that Equation 17 is set in boldface type and marked with an asterisk. Only these boldface equations are needed for analyzing aerometric data. The other equations are used to derive the working equations from fundamental concepts. The working equations are summarized at the end of this paper.

Carefully note that Equation 17 is a special definition of the standard geometric deviation. If a particular set of data is perfectly lognormally distributed, the same value of s_g will result regardless of the points selected for the computation; but if a particular set of data departs significantly from lognormality, the value of s_g calculated by Equation 17 will be strongly affected by the two points selected.

The above method for calculating the standard geometric deviation, in addition to having other advantages that will be mentioned later, eliminates the problem of dealing with concentrations at or near zero. The logarithm of zero is minus infinity. Equations 8 and 9 cannot be used with zero values. Observations near zero may not be accurate, but they can affect the calculated standard geometric deviation significantly if Equation 9 is used. Employing Equation 17 would eliminate the problem of inaccurate low values, since only the higher concentrations associated with the top third of the distribution would usually be used. In a relatively clean atmosphere only 15 percent of the concentrations measured might be above the instrument's minimum detectable level. In such cases, the 0.1- and 10-percentile points could be used for calculating the standard geometric deviation.

Table 11 shows the plotting positions of various percentiles in terms of the number of standard deviations between these percentiles and the median (top abscissa of Figure 3). This type of information is available for various percentiles in any standard statistical text. For 1-hour averages, Figure 3 and Tables 3 and 10 show that a sulfur dioxide concentration of 0.34 ppm was equaled or exceeded at the Washington CAMP site for 0.1 percent of the measurements during the period shown, and that 0.06 ppm was equaled or exceeded for 30 percent. Substituting this information into Equation 17 gives

$$s_{g\,\mathrm{hr}} = \exp\left[\frac{\ln(0.34/0.06)}{3.09 - 0.52}\right] \qquad (18)$$

$$s_{g\,\mathrm{hr}} = 1.96 \qquad (19)$$

CALCULATING THE GEOMETRIC MEAN

A line plotted on semi-logarithmic paper (Figure 3) can be expressed by the general equation[12]

$$y = jk^x \qquad (20)$$

where y = the ordinate value,

x = the abscissa value,

j = the intercept value of y when $x = 0$, and

k = the antilogarithm of the slope of the line (Equation 17).

Applying these concepts to Figure 3,

$$c = m_g s_g^{\,z} \qquad *(21)$$

Table 11. PLOTTING POSITION OF EXTREME CONCENTRATIONS AND PERCENTILES FOR SELECTED AVERAGING TIMES

Averaging time,		hr	No. of samples in year	Plotting position	
				Frequency (60%/N), percent of time	No. of standard deviations (z) from median
1	sec	0.000278	31,500,000	0.0000019	5.50
1	min	0.0166	525,000	0.0001142	4.73
5	min	0.0833	105,000	0.000571	4.39
8.8	min	0.146	60,000	0.001	4.27
10	min	0.166	52,500	0.001142	4.24
15	min	0.25	35,000	0.001715	4.14
30	min	0.5	17,500	0.00343	3.98
1	hr	1	8,760	0.00685	3.81
1.46	hr	1.46	6,000	0.01	3.72
2	hr	2	4,380	0.0137	3.63
3	hr	3	2,920	0.02055	3.53
8	hr	8	1,095	0.0548	3.26
12	hr	12	730	0.0822	3.14
14.6	hr	14.6	600	0.1	3.09
1	day	24	365	0.1644	2.94
2	day	48	183	0.328	2.72
4	day	96	91	0.657	2.48
5.9	day	146	60	1	2.33
7	day	168	52	1.153	2.27
14	day	346	26	2.31	1.99
1	mo	730	12	5	1.64
2	mo	1460	6	10	1.28
3	mo	2190	4	15	1.04
6	mo	4380	2	30	0.52
1	yr	8760	1	50	0.00

where z = the number of standard deviations between the particular frequency and the median (top abscissa of Figure 3).

The arithmetic mean can be used instead of the geometric mean by substituting Equation 11 into Equation 21.

$$c = ms_g^{\,z} - 0.5 \ln s_g \tag{22}$$

Equation 21 can be rearranged to solve for the geometric mean.

$$m_g = \frac{c}{s_g^{\,z}} \tag{23}$$

Taking logarithms,

$$\ln m_g = \ln c - z \ln s_g \tag{24}$$

Equation 23 can be used to solve for m_g for the example.

$$m_{g\,hr} = \frac{0.06}{1.96^{0.52}} \qquad (25)$$

$$m_{g\,hr} = 0.042 \text{ ppm}$$

This concentration is listed in column 3 of Table 10.

CALCULATING THE EXPECTED ANNUAL MAXIMUM CONCENTRATION

The frequency at which the expected annual maximum 1-hour concentration should be plotted (Figure 3) will now be treated. Consider a simpler situation first, that of plotting the frequency distribution for two 6-month average samples collected in a 12-month period. The first thought might be that the higher of the two values represents 50 percent of the data and that this value should thus be plotted at the 50-percentile point. The same reasoning would also place the low value at the 50-percentile point and thus an impossible vertical distribution line would be produced. The most probable location, however, for the high point should actually be somewhere between a frequency of 0 and 50 percent, and the low point should be plotted the same distance from the median on the opposite side of the distribution. An analysis of the data from a table of mean positions of ranked normal deviates[14] reveals that the high point should be plotted at a frequency of about 30 percent. If it were equally probable that the point could occur at 0 percent or at 50 percent, then the most probable location of the plotting position would be midway between the two, at 25 percent. Concentrations near the median, however, are expected to occur more frequently than are concentrations near the extremes. This fact moves the plotting position for the point in the example from the 25th percentile to a point near the 30th percentile. A simple empirical equation[13] for locating the plotting position for each point up to but not including the median has been developed from an analysis of the mentioned table.[14]

$$f = 100\% \frac{r - 0.4}{n} \qquad *(26)$$

where f = the plotting position frequency, in percent,

r = the rank order (highest, second, third, fourth, etc.), and

n = the number of samples.

The plotting position for the highest 1-hour averaging-time concentration in a year would thus be

$$f = 100\% \frac{1 - 0.4}{8760} \qquad (27)$$

$$f = 0.00685\% \qquad (28)$$

This frequency is a statistical z-value of 3.81 deviations from the median (Table 11 and Figure 3).

Now that the z-value is known, the expected annual maximum concentration can be calculated by using Equation 21.

$$c_{max\,hr} = 0.042(1.96)^{3.81} \qquad (29)$$

$$c_{max\,hr} = 0.55 \text{ ppm} \qquad (30)$$

When more significant digits are carried in a computer, a rounded value of 0.56 ppm results (Table 10, column 2).

Plotting positions, in terms of z-values, are available in statistical tables for sample sizes up to 50.[14] An exact, complex equation has been used to calculate z-values for any sample size by means of computerized numerical integration.[15] In almost all cases, the resulting z-values are within 0.01 of those determined with Equation 26. Resulting maximum concentrations for averaging times of 1 second to 1 month (such as those calculated in Equation 29, but using $s_{g\,hr} = 2$) are within 1 percent of what they would be if Equation 26 were used. For

averaging times of 5 minutes to 1 day the accuracy is within 0.3 percent. Since these accuracies are sufficient for air quality data, Equation 26 is recommended for use in all cases, instead of the exact, complex equation.

USING NON-CONTINUOUS DATA

Calculations thus far have been based on continuous air sampling data. The same results can be obtained using data from non-continuous sampling. The accuracy of the results will be related to the number of samples collected, compared with the number that would have been available had sampling been continuous. Equations and tables can be used to calculate confidence limits when non-continuous data are used.[16]

The standard geometric deviation and the geometric mean can be calculated from any two percentile points, as discussed previously. For smaller sets of data, a better fit to the arithmetic mean and the expected annual-maximum concentration might be determined by using the observed arithmetic mean and the observed maximum.

For instance, assume that a 24-hour sample of sulfur dioxide was taken every third day for a year. Since sampling every third day permits all days of the week to be sampled equally, this program would give completely randomized data. If all samples had been collected and analyzed successfully, the program would produce 121 samples. Assume that a dozen of them were lost, leaving 109 samples; that the highest 24-hour concentration measured was 0.15 ppm; and that the arithmetic mean was 0.05 ppm. The standard geometric deviation and the geometric mean can be calculated from these two values.

The plotting position for the maximum is first determined by using Equation 26.

$$f = 100\% \frac{1 - 0.4}{109} \tag{31}$$

$$f = 0.5505\% \tag{32}$$

Statistical tables similar to Table 11 indicate that this frequency is 2.54 deviations from the median.

The arithmetic mean can be used in these calculations if the right halves of Equations 12 and 23 are set equal to each other, terms are gathered, and the resulting quadratic equation is solved for $\ln s_g$. The resulting equation to use (since c is greater than m) is

$$\ln s_g = z - \left[z^2 - 2 \ln \left(\frac{c}{m}\right)\right]^{0.5} \tag{33}$$

Taking antilogarithms,

$$s_g = \exp \left\{z - \left[z^2 - 2 \ln \left(\frac{c}{m}\right)\right]^{0.5}\right\} \tag{*34}$$

where s_g = the standard geometric deviation,

z = the number of deviations the selected value is from the median,

c = the concentration of the selected value, and

m = the arithmetic mean concentration.

For the example,

$$s_{g\ \text{day}} = \exp\left\{2.54 - \left[2.54^2 - 2 \ln\left(\frac{0.15}{0.05}\right)\right]^{0.5}\right\} \tag{35}$$

$$s_{g\ \text{day}} = 1.61 \tag{36}$$

The geometric mean can now be calculated from Equation 23.

$$m_{g\ \text{day}} = \frac{0.15}{1.61^{2.54}} \tag{37}$$

$$m_{g\ \text{day}} = 0.045 \text{ ppm} \tag{38}$$

The expected annual maximum 1-day concentration can now be calculated from Equation 21.

$$c_{\text{max day}} = 0.045\ (1.61)^{2.94} \tag{39}$$

$$c_{\text{max day}} = 0.18 \text{ ppm} \tag{40}$$

The methods discussed in this section thus present an alternate technique, especially suited to non-continuous sampling, that can be used to calculate the standard geometric deviation, the geometric mean, and the expected annual maximum concentration for a particular averaging time, given the arithmetic mean concentration and a measured maximum or near-maximum concentration.

Several precautions must be taken when one is using non-continuous data. The first has already been mentioned—the fact that since somewhat less accurate results are obtained with non-continuous than with continuous sampling, the needed accuracy must be balanced against sampling program cost.[16]

A second precaution is required to ensure that the sampling program adequately represents the data. For instance, sulfur dioxide contributions from fuel combustion will be large in the winter and small in the summer. A program with sampling spaced equally throughout the year would give the most accurate representation for the year, although some evidence indicates that the annual mean may be close to the spring mean (March, April, and May) or the fall mean (September, October, and November), and that the standard geometric deviations obtained from spring-only or fall-only sampling may be comparable to those obtained from all-year sampling.[17]

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AVERAGING-TIME ANALYSES

Data analyses and statistical parameters for a single averaging time have been treated in previous sections. The following sections show how statistical parameters for one averaging time can be related to those for another averaging time. As one example, frequency distributions for 19 averaging times (Table 3) have been determined in the same manner as those described for 1-hour average concentrations and have been plotted by computer as the "+" points on Figure 4. Measured maximum and minimum values have been plotted as triangles. Each averaging time is about twice the previous one; thus, when plotted on logarithmic paper, they are approximately equally spaced along the abscissa.

For these analyses, all sampling times begin at midnight on December 1, 1961. The first 8-hour sample, for instance, is an average (rounded) of all the 5-minute values available from midnight to 8 a.m., the next from 8 a.m. to 4 p.m., the third from 4 p.m. to midnight, the fourth from midnight to 8 a.m. on December 2, etc. An average is calculated for a period only if half or more of the 5-minute values are available.

Because December, January, and February are the three coldest months of the year, fuel combustion for space heating and, thus, the concentrations of some combustion-related pollutants are highest during these months. For the particular analyses shown, a sampling period has been selected to begin on December 1 so that the 3-month averages shown in Table 3 will relate to winter (December, January, and February), spring (March, April, and May), summer (June, July, and August), and fall (September, October, and November). Splitting data into two calendar years causes some problems in data processing and computer programming, however; and, since past analyses have served the purpose of providing seasonal analyses for seven pollutants in eight cities (summarized in Tables 4 through 10), it no longer seems worth the trouble to continue analyzing data on a "pollution-year" rather than a calendar-year basis. For future analyses, therefore, the Federal Government is recommending, and using, sampling periods that begin on January 1 and end on December 31, whether for a single- or several-year period.

A MATHEMATICAL MODEL

Data have been analyzed and plotted by computer as a function of averaging time and frequency (Figure 4) for each year, and up to a 7-year period, for concentrations of carbon monoxide, hydrocarbons, nitric oxide, nitrogen dioxide, nitrogen oxides (NO + NO_2), oxidants, and sulfur dioxide for the CAMP sites in downtown Chicago, Cincinnati, Denver, Los Angeles, Philadelphia, St. Louis, San Francisco, and Washington. Analysis of these plots has resulted in a general mathematical model with the following characteristics:[13]

1. Concentrations are lognormally distributed for all averaging times.

2. The median concentration is proportional to averaging time raised to an exponent (and thus plots as a straight line on logarithmic paper).

3. The arithmetic mean concentration is the same for all averaging times.

4. For the longest averaging time calculated (usually 1 year), the arithmetic mean, geometric mean, maximum concentration, and minimum concentration are all equal (and thus plot at a single point on Figure 4).

5. Maximum concentration is approximately inversely proportional to averaging time raised to an exponent for averaging times of less than 1 month.

As mentioned previously, a model constructed from the 0.1- and 30-percent-frequency concentrations for 1-hour averages (* points on Figures 3 and 4) is expected to fit short-term maxima and the annual arithmetic

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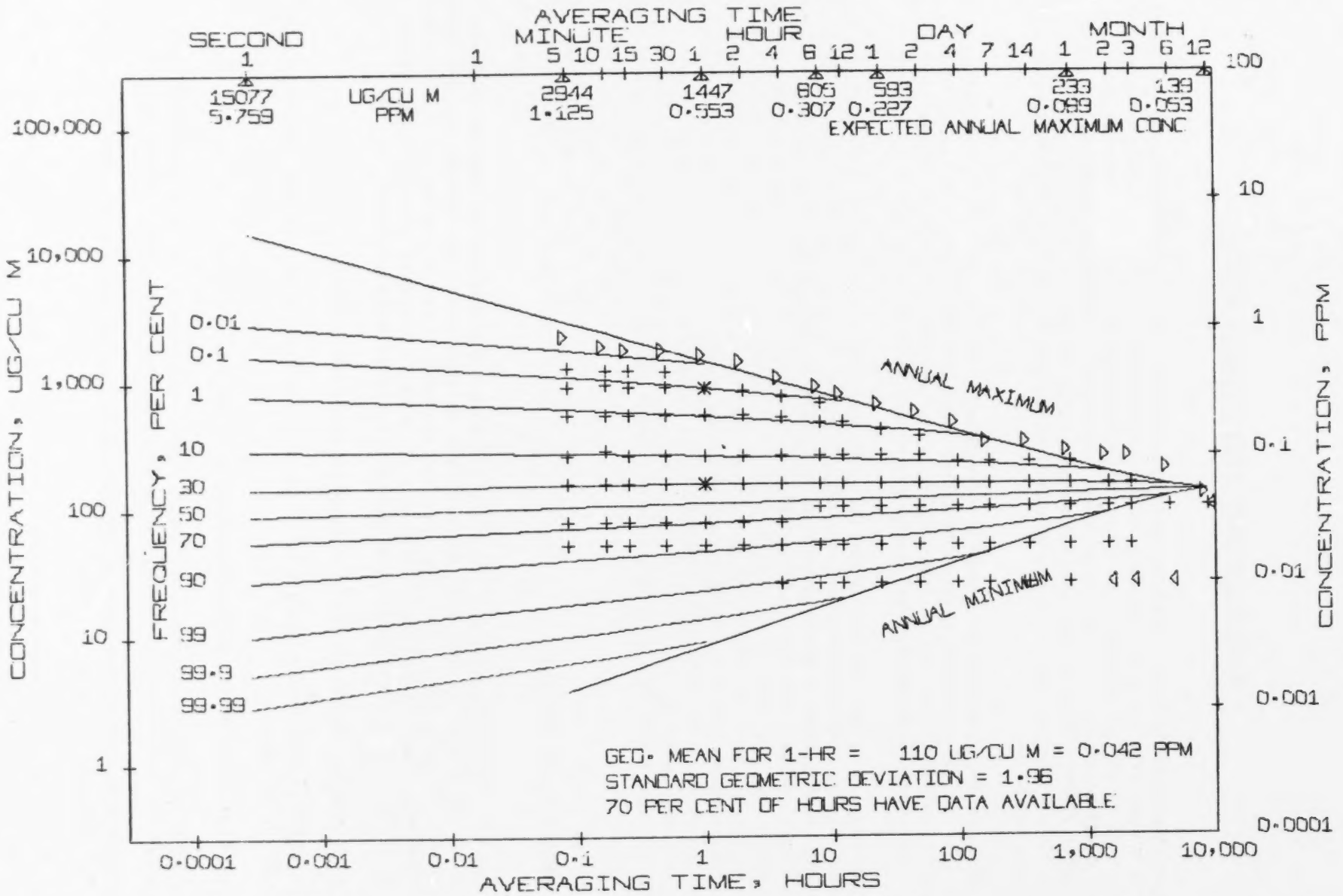

Figure 4. Computer plot of concentration versus averaging time and frequency for sulfur dioxide at site 256, Washington, D.C., December 1, 1961, to December 1, 1968.

mean very closely. A computer has been programmed with these two points and the above characteristics to plot the lines describing the model (Figure 4). If a particular set of data does not fit lognormality well, the model may inaccurately predict maxima for intermediate averaging times such as a week or a month. Fortunately, few air quality standards are specified for those averaging times, and the model thus seems especially suitable for the short-term (less than a few days) and long-term (1-year) averaging times that are commonly used.

For averaging times shorter than 1 hour, the maximum observed values are often less than the model predicts. An analysis of oxidant concentrations shows, for instance, that 5-minute maxima are about 1.2 to 1.6 times the 1-hour maxima, rather than about 2 times, as the model predicts.[4] One possible reason for this fall-off in oxidant concentration for short averaging times is that oxidant is a secondary rather than a primary pollutant; time is required for the photochemical reaction needed to produce oxidants. The reaction time may tend to dampen the fluctuations in concentrations and make them less than the fluctuations observed in primary pollutants.

Another effect on short-averaging-time concentrations results from instrument response time.[18] For instance, the nitrogen oxides instruments at the CAMP sites have a time constant of 10 minutes; this means that in each 10-minute period the sampler reading moves 63.2 percent of the remaining distance from the old concentration toward the new concentration to which the sampler is then being exposed. If the sampled concentration were abruptly changed from 0 to 1 ppm, in 10 minutes the sampler would read 0.63 ppm. Ten minutes later it would read 0.86 ppm. After 30 minutes, it would read 0.95 ppm, and so on. Although a computer could be used to compensate for instrument response time, the data reported here have not been so processed.

Another limitation of instrumentation appears as shorter and shorter averaging times are used, and the limit is finally reached when a sampler is measuring one molecule at a time; if the sampled molecule is the pollutant, then the concentration for that instant is 1 million ppm (100 percent). If the molecule is not the pollutant, the concentration is 0.

CALCULATING THE STANDARD GEOMETRIC DEVIATION

With the mathematical model, one can calculate the standard geometric deviation for any averaging time if it is known for another. The equation used to accomplish this was developed as follows: First, model characteristic number 2 states that the median concentration is proportional to averaging time raised to an exponent (and thus plots as a straight line on logarithmic paper). The slope, p, of a straight line on logarithmic graph paper[12] (Figure 4, 50-percentile line) is

$$p = \frac{\ln y_2 - \ln y_1}{\ln x_2 - \ln x_1} \tag{41}$$

For x_1 at averaging time t_a and x_2 at averaging time t_{total} the equation becomes

$$p = \frac{\ln m - \ln m_{ga}}{\ln t_{tot} - \ln t_a} \tag{42}$$

or

$$p = \frac{\ln (m/m_{ga})}{\ln (t_{tot}/t_a)} \tag{43}$$

where p = the slope of the median line (50th percentile),

m = the arithmetic mean,

m_{ga} = the geometric mean at averaging time a,

t_{tot} = the total averaging time (usually 1 year), and

t_a = averaging time a.

Equation 13 can be rearranged as

$$\ln\left(\frac{m}{m_g}\right) = 0.5 \ln^2 s_g \tag{44}$$

Substituting this expression into Equation 43, and expressing the results at two averaging times, t_a and t_b,

$$p = \frac{0.5 \ln^2 s_{ga}}{\ln (t_{tot}/t_a)} \tag{45}$$

$$p = \frac{0.5 \ln^2 s_{gb}}{\ln (t_{tot}/t_b)} \tag{46}$$

Setting the right halves of these two equations equal to each other and solving for s_{gb} gives:

$$s_{gb} = s_{ga}^{\left[\frac{\ln (t_{tot}/t_b)}{\ln (t_{tot}/t_a)}\right]^{0.5}} \tag{47}$$

The variable, v, could be substituted for the exponent to give:

$$s_{gb} = s_{ga}^{v^{0.5}} \tag{48}$$

where $$v = \frac{\ln (t_{tot}/t_b)}{\ln (t_{tot}/t_a)} \tag{49}$$

The mathematical model is completely described by any two of a number of aerometric parameters, whether at the same or at different averaging times. Model characteristic number 3 is applied if the two values are at different averaging times. Characteristic 3 states that the arithmetic mean is the same for all averaging times.

Equation 13 is:

$$\ln m = \ln m_g + 0.5 \ln^2 s_g \tag{13}$$

Equation 23 can be used to replace $\ln m_g$. This gives:

$$\ln m = \ln c - z \ln s_g + 0.5 \ln^2 s_g \tag{50}$$

Since $\ln m$ is the same for all averaging times, Equation 50 can be expressed for points at two different averaging times as:

$$\ln m = \ln c_a - z_a \ln s_{ga} + 0.5 \ln^2 s_{ga} \tag{51}$$

$$\ln m = \ln c_b - z_b \ln s_{gb} + 0.5 \ln^2 s_{gb} \tag{52}$$

The right halves of Equations 51 and 52 can be set equal to each other. Equation 48 can be used to replace s_{gb} and terms can be gathered to give:

$$0 = 0.5(1 - v) \ln^2 s_{ga} - (z_a - z_b v^{0.5}) \ln s_{ga} + \ln c_a - \ln c_b \tag{53}$$

A substitute variable, w, can be used as the coefficient for the second term.

$$w = z_a - z_b v^{0.5} \quad *(54)$$

The quadratic equation can be solved for $\ln s_{ga}$ to give:

$$\ln s_{ga} = \frac{w \pm [w^2 - 2(1 - v) \ln (c_a/c_b)]^{0.5}}{1 - v} \quad (55)$$

Antilogarithms can be taken to give:

$$s_{ga} = \exp \left\{ \frac{w \pm [w^2 - 2(1 - v) \ln (c_a/c_b)]^{0.5}}{1 - v} \right\} \quad *(56)$$

When c_b is greater than c_a, use the positive radical. When c_b is less than c_a, use the negative radical.

Equation 56 is used when the two input values to the mathematical model are from different averaging times. For instance, point $\underline{a}$ might be the 30-percentile concentration for 1-hour averages (previously used in Equation 18) and point $\underline{b}$ might be the 1-percentile concentration for 1-day averages (0.16 ppm, from Tables 3 and 10). The standard geometric deviation for the 1-hour averaging time at point $\underline{a}$ could then be calculated as follows.

Equation 49 could be used first to solve for v:

$$v = \frac{\ln (8760/24)}{\ln (8760/1)} \quad (57)$$

$$v = 0.65 \quad (58)$$

Equation 54 could be used next to solve for w:

$$w = 0.52 - 2.33(0.65)^{0.5} \quad (59)$$

$$w = -1.36 \quad (60)$$

Finally, the standard geometric deviation for the averaging time at point $\underline{a}$ could be determined with Equation 56.

$$s_{g\,\mathrm{hr}} = \exp \left\{ \frac{-1.36 + [(-1.36)^2 - 2(1 - 0.65)(\ln 0.06/0.16)]^{0.5}}{1 - 0.65} \right\} \quad (61)$$

$$s_{g\,\mathrm{hr}} = 1.94 \quad (62)$$

which is very close to the 1.96 calculated by Equation 19 from the 0.1- and 30-percentile concentrations of 1-hour averages.

As an additional application for Equations 49 through 56, the three national secondary standards for sulfur dioxide (Table 2) might be studied. These three standards have been plotted on Figure 5. The annual maximum concentration line has been drawn through the 3- and 24-hour standards. This line thus depicts the air quality expected at an air sampling site where these two concentrations are expected to occur once a year. The standard geometric deviation for such a site for 24-hour averages can be calculated by using Equations 49 through 56.

Point $\underline{a}$ will be the 24-hour standard and point $\underline{b}$ will be the 3-hour standard. Equation 49 can be used to calculate v:

$$v = \frac{\ln (8760/3)}{\ln (8760/24)} \quad (63)$$

$$v = 1.35 \quad (64)$$

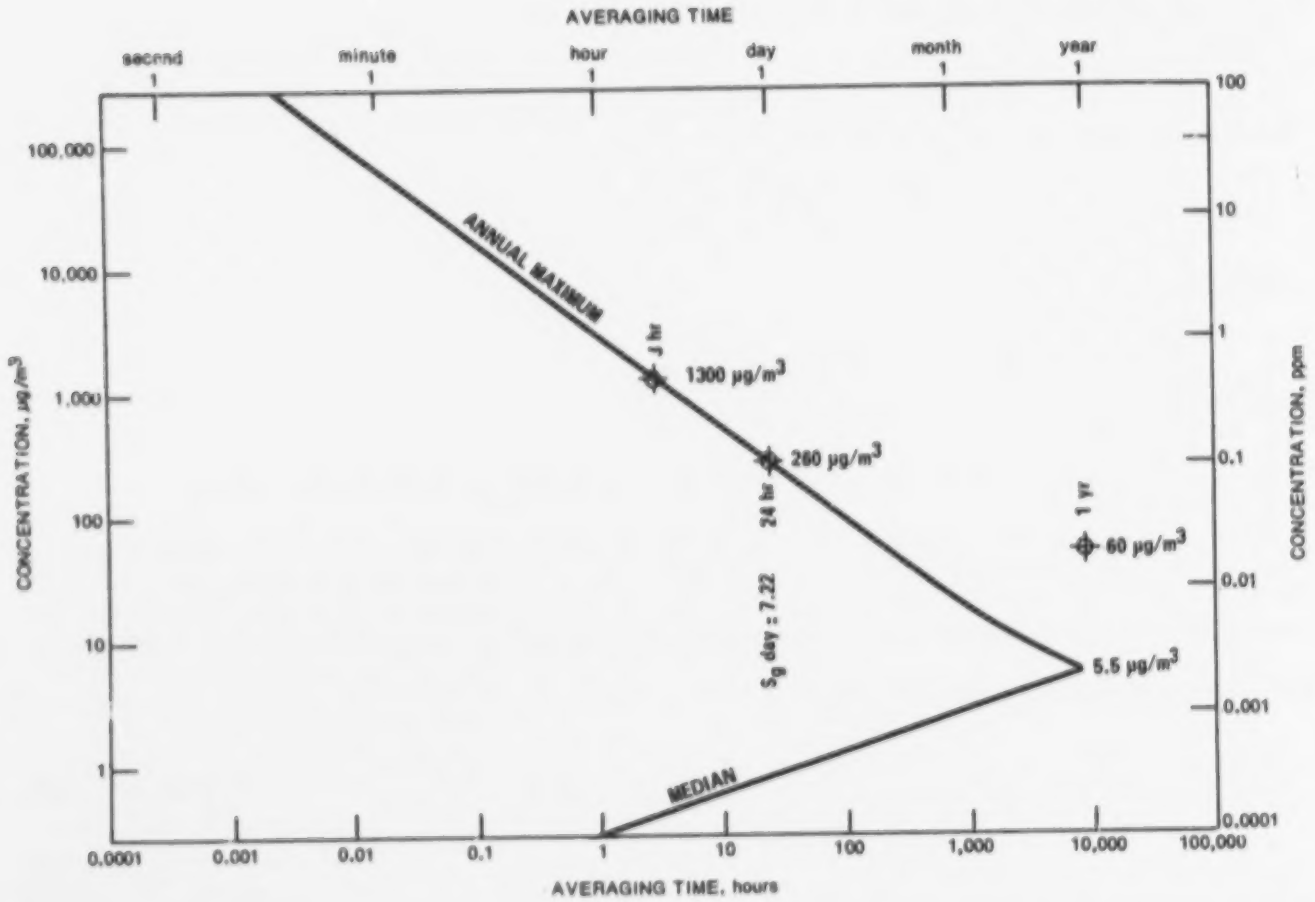

Figure 5. Expected annual maximum sulfur dioxide concentrations at sampling site where national secondary 3- and 24-hour-standard concentrations occur once a year.

Equation 54 can be used to calculate w. The value of z_a is 2.94 (Table 11). Equation 26 is used to determine z_b:

$$f = 100\% \frac{1 - 0.4}{2920} \tag{65}$$

$$f = 0.02055\% \tag{66}$$

Most statistics texts list frequency as a portion of 1 rather than as a portion of 100 percent. Expressed in these terms,

$$f = 0.0002055 \tag{67}$$

Most statistics texts also measure frequency starting with the low values and going to the high values, whereas here we are going in the opposite direction. The statistics texts would thus list this value as

$$f = 1 - 0.0002055 \tag{68}$$

$$f = 0.9997945 \tag{69}$$

The z value associated with this frequency is 3.53. This information can now be substituted into Equation 54:

$$w = 2.94 - 3.53(1.35)^{0.5} \tag{70}$$

$$w = -1.16$$

The standard geometric deviation for 24-hour averages can now be calculated with Equation 56:

$$s_g \text{ day} = \exp\left\{\frac{-1.16 + [(-1.16)^2 - 2(1 - 1.35)(\ln 260/1300)]^{0.5}}{1 - 1.35}\right\} \quad (71)$$

$$s_g \text{ day} = 7.22$$

Thus, for 24-hour averages at an air sampling site, if the standard geometric deviation were 7.22 and the annual maximum concentration were 260 $\mu g/m^3$, then the annual maximum concentration expected for 3-hour averages would be 1300 $\mu g/m^3$.

The expected annual mean could be calculated by rearranging Equation 22 to solve for m.

$$m = cs_g^{0.5 \ln s_g - z} \quad (72)$$

$$m = 260(7.22)^{0.5 \ln 7.22 - 2.94}$$

$$m = 5.5\ \mu g/m^3$$

Thus, if the 3- and 24-hour standard concentrations each occurred at a given site once a year, then the annual arithmetic mean concentration expected at that site would be 5.5 $\mu g/m^3$, which is far below the allowable standard of 60 $\mu g/m^3$.

Any two air quality standards for a given pollutant can be inserted into the mathematical model to determine the standard geometric deviation that occurs when both standards are achieved simultaneously. This deviation can be compared with the deviation determined by analyzing aerometric data for a particular air sampling site. If the measured deviation is less than that calculated from the two standards, then the longer averaging time standard will require the greatest source reduction at that site and could be called the "controlling standard." If the measured deviation is greater than the one calculated from the two standards, the shorter averaging time standard will control.

If one of the standards is an arithmetic mean, then Equation 34 can be used to determine the standard geometric deviation at which the "controlling standard" will switch from one standard to the other. This equation could be used to determine when the controlling standard switches from the 24-hour sulfur dioxide standard of 260 $\mu g/m^3$ to the annual arithmetic mean standard of 60 $\mu g/m^3$.

$$s_g \text{ day} = \exp\left\{2.94 - \left[2.94^2 - 2 \ln\left(\frac{260}{60}\right)\right]^{0.5}\right\} \quad (73)$$

$$s_g \text{ day} = 1.73 \quad (74)$$

Thus, if the standard geometric deviation for 24-hour averages is less than 1.73, the annual mean standard is the "controlling standard," and if the deviation is more than 1.73, the 24-hour standard controls.

The standard geometric deviation at which the "controlling standard" switches from one standard to another has been calculated for the national standards and listed in Table 12 for the three pollutants that have two or more standards (carbon monoxide, particulate matter, and sulfur dioxide). These deviations can be compared with the minimum, median, and maximum deviations measured for the CAMP stations for carbon monoxide (Table 4) and sulfur dioxide (Table 10). Such a comparison can suggest how frequently one of the two standards is expected to "control" implementation plans and control strategies for achieving the standards. The controlling deviation for carbon monoxide is 4.60. Since this is greater than the median value of 1.47, the 8-hour standard is expected to apply more than half of the time. In fact, the controlling deviation of 4.60 is so much higher than the 1.70 maximum measured at any CAMP station that the 1-hour standard will probably never affect any outdoor source reduction plans.

Table 12. STANDARD GEOMETRIC DEVIATIONS AT WHICH "CONTROL" SWITCHES FROM ONE STANDARD TO ANOTHER

Pollutant	Type of standard	Standards: Annual maximum for avg. time, $\mu g/m^3$					Standards: Annual geom. mean of 24-hr averages, $\mu g/m^3$	s_g day if both stds achieved at same time	CAMP[a] s_g day		
		1 hr	3 hr	8 hr	24 hr	1 yr			Min	Med	Max
Carbon monoxide	Primary and secondary	40,000		10,000[b]				4.60	1.36	1.47	1.70
Hydrocarbons (nonmethane)	Primary and secondary		160 (6 to 9 a.m.)								
Nitrogen dioxide	Primary and secondary					100					
Oxidants	Primary and secondary	160									
Particulate matter	Primary				260		75[b]	1.53	1.25	1.50	2.00
	Secondary				150[b]		60	1.37			
Sulfur dioxide	Primary				365[b]	80		1.77	1.72	1.84	2.12
	Secondary		1300		260[b]			7.22			
					260[b]	60		1.73			

[a] Approximate deviations observed on National Air Surveillance Network data are listed for particulate matter.

[b] Air quality standard that is expected to "control" at more than half of air sampling sites.

A similarly high deviation, 7.22, is calculated for the 3- and 24-hour sulfur dioxide standards; thus the 24-hour standard would always be expected to control source reduction plans. This calculation is, however, based on the assumption that the aerometric data fit the mathematical model. The model in turn has been based on concentrations in urban atmospheres that are affected by many sources of a pollutant. It is conceivable that concentration patterns near an isolated, strong, high source of sulfur dioxide might cause the 3-hour standard to control at a few sites in the Nation.

The controlling standard deviation for the 24-hour and annual arithmetic mean sulfur dioxide standards is 1.73, almost the same as the minimum deviation of 1.72 observed at the CAMP stations. This observation coupled with that from the previous paragraph suggests that the 24-hour sulfur dioxide standard will almost always be the controlling standard when implementation plans for achieving the standards are being devised.

CALCULATING THE GEOMETRIC MEAN

The geometric mean for one averaging time can be calculated from information for another averaging time by use of the equations that follow.

Model characteristic number 2 states that the median concentration is proportional to averaging time raised to an exponent (and thus plots as a straight line on logarithmic paper). The slope of this median (geometric mean) line expressed as a function of parameters for averaging time $\underline{a}$ (Equation 42) can also be written with parameters for averaging time $\underline{b}$. Since the slope is the same at both averaging times, the right halves of both equations can be set equal to each other and solved for $\ln m_{gb}$.

$$\ln m_{gb} = v \ln \frac{m_{ga}}{m} + \ln m \tag{75}$$

Antilogarithms can be taken to give:

$$m_{gb} = m \left(\frac{m_{ga}}{m}\right)^{v} \tag{*76}$$

where $$v = \frac{\ln(t_{tot}/t_b)}{\ln(t_{tot}/t_a)} \tag{49}$$

Equation 76 thus gives the geometric mean at averaging time *b* as a function of the arithmetic mean (the same for all averaging times), *v*, and the geometric mean at averaging time *a*.

The geometric mean at averaging time *b* can also be expressed as a function of the geometric mean and standard geometric deviation at *a*. Equation 75 is first rearranged as:

$$\ln m_{gb} = (\ln m)(1 - v) + v \ln m_{ga} \tag{77}$$

By using Equation 13, $\ln m$ can be replaced. Solving for $\ln m_{gb}$ then gives:

$$\ln m_{gb} = \ln m_{ga} + 0.5(1 - v) \ln^2 s_{ga} \tag{78}$$

Taking antilogarithms gives:

$$m_{gb} = m_{ga} \exp\left[0.5(1 - v) \ln^2 s_{ga}\right] \tag{*79}$$

or

$$m_{gb} = m_{ga} s_{ga}^{0.5(1 - v) \ln s_{ga}} \tag{80}$$

For 1-hour averages of sulfur dioxide concentrations in Washington, Equation 19 and Table 10 indicate that the standard geometric deviation is 1.96 and that the geometric mean is 0.042 ppm (Equation 25 and column 3 of Table 10).

The geometric mean for 1-day averages can be calculated by using Equation 79:

$$v = \frac{\ln (8760/24)}{\ln (8760/1)} \tag{81}$$

$$v = 0.65$$

$$m_{g\,\text{day}} = 0.042(1.96) \exp[0.5\,(1 - 0.65) \ln^2 1.96] \tag{82}$$

$$m_{g\,\text{day}} = 0.045 \tag{83}$$

which is very close to the value of 0.046 ppm calculated by computer and listed in column 3 of Table 10.

PLOTTING RESULTS

Equations 17, 21, 23, 48, and 79 have been used, together with the 0.1- and 30-percentile concentrations measured for 1-hour averages, to plot all of the lines on Figure 4 and to calculate all of the values in columns 2 through 4 in Tables 4 through 10 (the other values in Tables 4 through 10 were measured). The data have been plotted and tabulated for a total time (t_{tot}) of 1 year so that the expected annual maximum concentrations could be easily compared with air quality standards. The model could have been used to predict maxima expected for

any other period, such as a decade. For most instances, however, it is suggested that the model be used as shown in Figure 4 to depict expected annual maximum concentrations.

Figure 4 shows expected annual maximum concentrations both graphically (as the top plotted line) and digitally (along the top abscissa). Concentrations are given both in $\mu g/m^3$ and in ppm. The values along the top abscissa indicate, for instance, that the annual maximum 1-second concentration is expected to be 5.76 ppm. This parameter could be used if the odor of sulfur dioxide were to be controlled, for instance.[6] The values on the top abscissa in Figure 4 and in Table 10 indicate that the expected annual maximum 1-hour concentration is 0.56 ppm, the expected annual maximum 1-day concentration is 0.23 ppm, and the expected annual mean is 0.053 ppm. Values in Figure 4 and Table 10 vary to a slight but unimportant degree because of slightly different sequences in computer calculations.

As mentioned earlier, *the values in column 2 of Tables 4 through 10 are suggested as design values for use in relating aerometric data to air quality standards, control strategies, and implementation plans.*

SHORT CUTS

Model characteristic number 5 indicates that the expected annual maximum concentration is approximately inversely proportional to averaging time raised to an exponent for periods of less than 1 month. If the standard geometric deviation and the expected annual maximum concentration for a particular averaging time at a particular sampling site are known, then the expected annual maxima for other averaging times can be estimated[13] by using the equation:

$$c_{max} = c_{max\ hr} t^{q} \qquad *(84)$$

where c_{max} = the expected annual maximum concentration for a particular averaging time,

$c_{max\ hr}$ = the expected annual maximum 1-hour concentration,

t = the averaging time, and

q = the slope of the maximum line on logarithmic paper (Figure 4).

The slope of the annual maximum line can be determined from any two points. To illustrate the use of the equation, averaging times of 1 hour and 1 day have been selected and the slope has been calculated as a function of the standard geometric deviation for 1-hour averaging time (Table 13).[13] The expected annual maximum 1-month concentration could be calculated by using Table 13 and the previously calculated maximum 1-hour concentration (Equation 30):

$$c_{max\ mo} = 0.55(730)^{-0.279} \text{ ppm} \qquad (85)$$

$$c_{max\ mo} = 0.087 \text{ ppm} \qquad (86)$$

which is quite close to the 0.089 ppm read from the top abscissa of Figure 4.

Relationships among standard geometric deviations and expected annual maximum concentrations have been calculated for several averaging times (Table 14).[7] Calculations have been made for 0.05-unit increments of 1-hour standard geometric deviations. For example, the 1-hour standard geometric deviation for sulfur dioxide at the Washington CAMP site is 1.96 and the annual mean is 0.053 ppm (top abscissa, Figure 4). The expected annual maximum concentration for 1-day averages at that site can be determined by using Table 14. The 1.96 value is one-fifth of the distance from the 1.95 value toward the 2.00 value listed in column 3 of Table 14. Similarly, the maximum-to-mean ratio of 4.25 is one-fifth of the distance between the values of 4.21 and 4.42 listed under 1-day ratios. The expected annual maximum 1-day concentration would thus be 4.25 times the annual mean of 0.053 ppm, or 0.23 ppm, which agrees with the 0.227 read from the top abscissa on Figure 4.

Table 13. SLOPE OF MAXIMUM CONCENTRATION LINE FOR 1-HR AVERAGE STANDARD GEOMETRIC DEVIATIONS FROM 1.0 THROUGH 4.99

SGD[a]	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
1.00	0.000	−0.004	−0.008	−0.012	−0.017	−0.021	−0.025	−0.029	−0.034	−0.038
1.10	−0.042	−0.046	−0.050	−0.054	−0.057	−0.061	−0.065	−0.069	−0.072	−0.076
1.20	−0.080	−0.083	−0.087	−0.090	−0.094	−0.097	−0.101	−0.104	−0.107	−0.111
1.30	−0.114	−0.117	−0.121	−0.124	−0.127	−0.130	−0.133	−0.136	−0.139	−0.142
1.40	−0.145	−0.148	−0.151	−0.154	−0.157	−0.160	−0.163	−0.165	−0.168	−0.171
1.50	−0.174	−0.176	−0.179	−0.182	−0.184	−0.187	−0.190	−0.192	−0.195	−0.197
1.60	−0.200	−0.202	−0.205	−0.207	−0.210	−0.212	−0.214	−0.217	−0.219	−0.222
1.70	−0.224	−0.226	−0.229	−0.231	−0.233	−0.235	−0.238	−0.240	−0.242	−0.244
1.80	−0.246	−0.248	−0.251	−0.253	−0.255	−0.257	−0.259	−0.261	−0.263	−0.265
1.90	−0.267	−0.269	−0.271	−0.273	−0.275	−0.277	−0.279	−0.281	−0.283	−0.285
2.00	−0.287	−0.288	−0.290	−0.292	−0.294	−0.296	−0.298	−0.299	−0.301	−0.303
2.10	−0.305	−0.307	−0.308	−0.310	−0.312	−0.314	−0.315	−0.317	−0.319	−0.320
2.20	−0.322	−0.324	−0.325	−0.327	−0.329	−0.330	−0.332	−0.333	−0.335	−0.337
2.30	−0.338	−0.340	−0.341	−0.343	−0.344	−0.346	−0.347	−0.349	−0.350	−0.352
2.40	−0.353	−0.355	−0.356	−0.358	−0.359	−0.361	−0.362	−0.364	−0.365	−0.366
2.50	−0.368	−0.369	−0.371	−0.372	−0.373	−0.375	−0.376	−0.378	−0.379	−0.380
2.60	−0.382	−0.383	−0.384	−0.386	−0.387	−0.388	−0.390	−0.391	−0.392	−0.393
2.70	−0.395	−0.396	−0.397	−0.398	−0.400	−0.401	−0.402	−0.403	−0.405	−0.406
2.80	−0.407	−0.408	−0.410	−0.411	−0.412	−0.413	−0.414	−0.415	−0.417	−0.418
2.90	−0.419	−0.420	−0.421	−0.422	−0.424	−0.425	−0.426	−0.427	−0.428	−0.429
3.00	−0.430	−0.431	−0.432	−0.434	−0.435	−0.436	−0.437	−0.438	−0.439	−0.440
3.10	−0.441	−0.442	−0.443	−0.444	−0.445	−0.446	−0.447	−0.448	−0.449	−0.450
3.20	−0.451	−0.452	−0.453	−0.454	−0.455	−0.456	−0.457	−0.458	−0.459	−0.460
3.30	−0.461	−0.462	−0.463	−0.464	−0.465	−0.466	−0.467	−0.468	−0.469	−0.470
3.40	−0.471	−0.472	−0.473	−0.474	−0.475	−0.476	−0.477	−0.477	−0.478	−0.479
3.50	−0.480	−0.481	−0.482	−0.483	−0.484	−0.485	−0.485	−0.486	−0.487	−0.488
3.60	−0.489	−0.490	−0.491	−0.492	−0.492	−0.493	−0.494	−0.495	−0.496	−0.497
3.70	−0.497	−0.498	−0.499	−0.500	−0.501	−0.502	−0.502	−0.503	−0.504	−0.505
3.80	−0.506	−0.506	−0.507	−0.508	−0.509	−0.510	−0.510	−0.511	−0.512	−0.513
3.90	−0.514	−0.514	−0.515	−0.516	−0.517	−0.517	−0.518	−0.519	−0.520	−0.520
4.00	−0.521	−0.522	−0.523	−0.523	−0.524	−0.525	−0.526	−0.526	−0.527	−0.528
4.10	−0.529	−0.529	−0.530	−0.531	−0.531	−0.532	−0.533	−0.533	−0.534	−0.535
4.20	−0.536	−0.536	−0.537	−0.538	−0.539	−0.539	−0.540	−0.541	−0.541	−0.542
4.30	−0.543	−0.543	−0.544	−0.545	−0.545	−0.546	−0.547	−0.547	−0.548	−0.549
4.40	−0.549	−0.550	−0.551	−0.551	−0.552	−0.553	−0.553	−0.554	−0.555	−0.555
4.50	−0.556	−0.556	−0.557	−0.558	−0.558	−0.559	−0.560	−0.560	−0.561	−0.562
4.60	−0.562	−0.563	−0.563	−0.564	−0.565	−0.565	−0.566	−0.566	−0.567	−0.568
4.70	−0.568	−0.569	−0.569	−0.570	−0.571	−0.571	−0.572	−0.572	−0.573	−0.574
4.80	−0.574	−0.575	−0.575	−0.576	−0.576	−0.577	−0.578	−0.578	−0.579	−0.579
4.90	−0.580	−0.580	−0.581	−0.582	−0.582	−0.583	−0.583	−0.584	−0.584	−0.585

[a]Standard geometric deviation for a particular slope is the sum of the left and top margin values.

NON-LOGNORMALLY DISTRIBUTED DATA

Model characteristic number 1 states that concentrations are lognormally distributed over all averaging times. This general trend, subject to the limitations noted earlier, is based on data collected at CAMP stations near the centers of large cities. The model has also been designed so that accurate predictions of expected annual maxima will be made for the most frequently used averaging times even if a particular set of data departs markedly from lognormality. Aerometric data sampled from sites near strong, isolated sources are often not lognormally distributed, however, and one must ensure that grossly inaccurate predictions are not made from model characterizations of these data. At some future time, a special mathematical model may be developed for describing air quality as a function of averaging time and frequency for these strong, isolated sources.

Table 14. RATIO OF EXPECTED ANNUAL MAXIMUM POLLUTANT CONCENTRATION TO ARITHMETIC MEAN CONCENTRATION FOR VARIOUS AVERAGING TIMES AND STANDARD GEOMETRIC DEVIATIONS

Standard geometric deviation for averaging times of:								Ratio of annual maximum concentration to mean concentration for averaging times of:							
1 sec	5 min	1 hr	3 hr	8 hr	1 day	4 days	1 mo	1 sec	5 min	1 hr	3 hr	8 hr	1 day	4 days	1 mo
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.07	1.06	1.05	1.05	1.04	1.04	1.04	1.03	1.44	1.27	1.20	1.17	1.15	1.12	1.09	1.04
1.14	1.11	1.10	1.09	1.09	1.08	1.07	1.05	2.04	1.59	1.43	1.37	1.31	1.25	1.18	1.08
1.21	1.17	1.15	1.14	1.13	1.12	1.10	1.08	2.83	1.97	1.69	1.57	1.48	1.38	1.27	1.12
1.29	1.23	1.20	1.19	1.17	1.16	1.14	1.10	3.86	2.42	1.97	1.80	1.66	1.52	1.36	1.16
1.36	1.29	1.25	1.23	1.22	1.20	1.17	1.12	5.18	2.93	2.28	2.05	1.86	1.67	1.46	1.20
1.44	1.34	1.30	1.28	1.26	1.24	1.20	1.15	6.85	3.51	2.63	2.31	2.06	1.82	1.56	1.24
1.51	1.40	1.35	1.32	1.30	1.27	1.24	1.17	8.94	4.18	3.00	2.60	2.28	1.98	1.65	1.28
1.59	1.46	1.40	1.37	1.34	1.31	1.27	1.19	11.53	4.93	3.41	2.90	2.51	2.14	1.75	1.31
1.67	1.52	1.45	1.42	1.39	1.35	1.30	1.21	14.69	5.77	3.84	3.22	2.75	2.31	1.85	1.35
1.75	1.58	1.50	1.46	1.43	1.39	1.33	1.24	18.53	6.71	4.32	3.56	3.00	2.48	1.95	1.38
1.83	1.64	1.55	1.51	1.47	1.42	1.36	1.26	23.14	7.76	4.82	3.92	3.26	2.65	2.05	1.42
1.91	1.70	1.60	1.55	1.51	1.46	1.39	1.28	28.65	8.92	5.37	4.30	3.53	2.84	2.15	1.45
1.99	1.76	1.65	1.60	1.55	1.50	1.42	1.30	35.16	10.19	5.95	4.70	3.81	3.02	2.26	1.48
2.08	1.82	1.70	1.64	1.59	1.53	1.45	1.32	42.83	11.58	6.56	5.12	4.10	3.21	2.36	1.52
2.16	1.88	1.75	1.69	1.63	1.57	1.48	1.34	51.78	13.11	7.21	5.55	4.40	3.40	2.46	1.55
2.25	1.94	1.80	1.74	1.68	1.61	1.51	1.36	62.18	14.76	7.90	6.01	4.71	3.60	2.57	1.58
2.34	2.00	1.85	1.78	1.72	1.64	1.54	1.38	74.18	16.56	8.62	6.49	5.03	3.80	2.67	1.61
2.42	2.06	1.90	1.83	1.76	1.68	1.57	1.40	87.96	18.50	9.39	6.98	5.36	4.00	2.77	1.64
2.51	2.12	1.95	1.87	1.80	1.71	1.60	1.42	103.70	20.59	10.19	7.49	5.70	4.21	2.88	1.67
2.60	2.19	2.00	1.92	1.84	1.75	1.63	1.44	121.61	22.83	11.03	8.03	6.04	4.42	2.98	1.70
2.69	2.25	2.05	1.96	1.88	1.78	1.66	1.46	141.88	25.24	11.91	8.58	6.40	4.64	3.09	1.73
2.78	2.31	2.10	2.00	1.92	1.82	1.69	1.47	164.73	27.81	12.83	9.15	6.76	4.85	3.19	1.75
2.87	2.37	2.15	2.05	1.96	1.85	1.72	1.49	190.39	30.55	13.78	9.74	7.14	5.07	3.30	1.78
2.97	2.43	2.20	2.09	2.00	1.89	1.74	1.51	219.09	33.47	14.78	10.34	7.52	5.29	3.40	1.81
3.06	2.50	2.25	2.14	2.04	1.92	1.77	1.53	251.07	36.56	15.81	10.97	7.91	5.52	3.51	1.83
3.15	2.56	2.30	2.18	2.08	1.96	1.80	1.55	286.61	39.84	16.89	11.61	8.30	5.75	3.61	1.86
3.25	2.62	2.35	2.23	2.12	1.99	1.83	1.56	325.94	43.31	18.00	12.27	8.71	5.98	3.72	1.88
3.34	2.69	2.40	2.27	2.16	2.03	1.85	1.58	369.37	46.97	19.15	12.94	9.12	6.21	3.82	1.91
3.44	2.75	2.45	2.32	2.20	2.06	1.88	1.60	417.15	50.82	20.34	13.64	9.54	6.44	3.93	1.93
3.54	2.81	2.50	2.36	2.24	2.09	1.91	1.62	469.60	54.88	21.57	14.35	9.97	6.68	4.03	1.96
3.64	2.88	2.55	2.41	2.27	2.13	1.93	1.63	527.00	59.14	22.84	15.07	10.40	6.92	4.13	1.98
3.74	2.94	2.60	2.45	2.31	2.16	1.96	1.65	589.67	63.60	24.14	15.82	10.84	7.16	4.24	2.00
3.83	3.00	2.65	2.49	2.35	2.19	1.99	1.67	657.92	68.28	25.49	16.58	11.28	7.40	4.34	2.03
3.93	3.07	2.70	2.54	2.39	2.23	2.01	1.68	732.07	73.17	26.87	17.35	11.74	7.64	4.44	2.05
4.04	3.13	2.75	2.58	2.43	2.26	2.04	1.70	812.47	78.28	28.29	18.14	12.20	7.89	4.55	2.07
4.14	3.20	2.80	2.63	2.47	2.29	2.07	1.71	899.45	83.61	29.75	18.95	12.66	8.13	4.65	2.09
4.24	3.26	2.85	2.67	2.51	2.33	2.09	1.73	993.34	89.16	31.24	19.77	13.13	8.38	4.75	2.11
4.34	3.33	2.90	2.71	2.55	2.36	2.12	1.75	1094.51	94.94	32.78	20.60	13.61	8.63	4.86	2.13
4.45	3.39	2.95	2.76	2.59	2.39	2.14	1.76	1203.31	100.94	34.35	21.45	14.09	8.88	4.96	2.16
4.55	3.46	3.00	2.80	2.62	2.42	2.17	1.78	1320.11	107.17	35.95	22.32	14.58	9.13	5.06	2.18
4.66	3.52	3.05	2.84	2.66	2.46	2.20	1.79	1445.27	113.64	37.60	23.20	15.07	9.38	5.16	2.20
4.76	3.59	3.10	2.89	2.70	2.49	2.22	1.81	1579.16	120.34	39.28	24.09	15.57	9.64	5.26	2.22
4.87	3.65	3.15	2.93	2.74	2.52	2.25	1.82	1722.17	127.28	40.99	25.00	16.07	9.89	5.36	2.24
4.97	3.72	3.20	2.98	2.78	2.55	2.27	1.84	1874.68	134.46	42.74	25.92	16.57	10.15	5.46	2.25

Table 14(Continued). RATIO OF EXPECTED ANNUAL MAXIMUM POLLUTANT CONCENTRATION TO ARITHMETIC MEAN CONCENTRATION FOR VARIOUS AVERAGING TIMES AND STANDARD GEOMETRIC DEVIATIONS

Standard geometric deviation for averaging times of:								Ratio of annual maximum concentration to mean concentration for averaging times of:							
1 sec	5 min	1 hr	3 hr	8 hr	1 day	4 days	1 mo	1 sec	5 min	1 hr	3 hr	8 hr	1 day	4 days	1 mo
5.08	3.78	3.25	3.02	2.81	2.59	2.30	1.85	2037.07	141.87	44.53	26.85	17.09	10.40	5.56	2.27
5.19	3.85	3.30	3.06	2.85	2.62	2.32	1.87	2209.73	149.53	46.35	27.79	17.60	10.66	5.66	2.29
5.30	3.91	3.35	3.11	2.89	2.65	2.35	1.88	2393.06	157.43	48.20	28.75	18.12	10.92	5.76	2.31
5.41	3.98	3.40	3.15	2.93	2.68	2.37	1.90	2587.45	165.58	50.09	29.72	18.65	11.18	5.86	2.33
5.52	4.05	3.45	3.19	2.97	2.71	2.39	1.91	2793.31	173.97	52.01	30.71	19.17	11.44	5.96	2.35
5.63	4.11	3.50	3.24	3.00	2.75	2.42	1.93	3011.02	182.61	53.96	31.70	19.71	11.70	6.05	2.36
5.74	4.18	3.55	3.28	3.04	2.78	2.44	1.94	3241.01	191.50	55.95	32.71	20.24	11.96	6.15	2.38
5.85	4.24	3.60	3.32	3.08	2.81	2.47	1.95	3483.66	200.63	57.97	33.72	20.78	12.22	6.25	2.40
5.96	4.31	3.65	3.37	3.12	2.84	2.49	1.97	3739.39	210.02	60.02	34.75	21.32	12.48	6.34	2.41
6.08	4.38	3.70	3.41	3.15	2.87	2.52	1.98	4008.61	219.65	62.11	35.79	21.87	12.74	6.44	2.43
6.19	4.44	3.75	3.45	3.19	2.90	2.54	2.00	4291.72	229.54	64.22	36.84	22.42	13.00	6.53	2.45
6.30	4.51	3.80	3.50	3.23	2.93	2.56	2.01	4589.13	239.67	66.37	27.90	22.97	13.26	6.63	2.46
6.42	4.58	3.85	3.54	3.27	2.96	2.59	2.02	4901.25	250.06	68.55	38.97	23.53	13.53	6.72	2.48
6.53	4.65	3.90	3.58	3.30	3.00	2.61	2.04	5228.49	260.70	70.75	40.05	24.09	13.79	6.82	2.49
6.65	4.71	3.95	3.63	3.34	3.03	2.63	2.05	5571.26	271.59	72.99	41.14	24.65	14.05	6.91	2.51

SUMMARY

Information on air quality measurements, air pollutant effects, air quality criteria, and air quality standards can all be expressed as a concentration function of averaging time and frequency. This type of information has been presented here in tables and on graphs.

The frequency with which certain concentration values are equaled or exceeded has been discussed in terms of the lognormal distribution. Air quality data have been related to air quality standards with calculated geometric means, standard geometric deviations, and the expected annual maximum concentrations from both continuous and non-continuous data.

Air pollutant effects vary with exposure durations, and these durations can be related in turn to current air quality data by averaging measured pollutant concentrations over various time periods. A mathematical model for describing the relationship among concentration values for various averaging times has been described. Results of calculations with the model have been plotted and various short cuts for speeding the analysis of aerometric data have been discussed.

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APPENDIX: WORKING EQUATIONS AND EXERCISES WITH ANSWERS

EQUATIONS

Many equations have been used here in order to establish the fundamental concepts needed to develop the working equations actually used in analyzing aerometric data. The twelve working equations that follow are the only ones actually needed for analysis.

The following five equations can be used to analyze data collected for one averaging time:

$$s_g = \exp\left[\frac{\ln (c_h/c_i)}{z_h - z_i}\right] \tag{17}$$

$$s_g = \exp\left\{z - \left[z^2 - 2 \ln \left(\frac{c}{m}\right)\right]^{0.5}\right\} \tag{34}$$

$$m_g = \frac{c}{s_g{}^z} \tag{23}$$

$$c = m_g s_g{}^z \tag{21}$$

$$f = 100\% \frac{r - 0.4}{n} \tag{26}$$

The following seven equations can be used to calculate values for one averaging time from values that are available for another averaging time.

$$s_{gb} = s_{ga}{}^{v^{0.5}} \tag{48}$$

$$s_{ga} = \exp\left\{\frac{w \pm [w^2 - 2(1 - v) \ln (c_a/c_b)]^{0.5}}{1 - v}\right\} \tag{56}$$

$$v = \frac{\ln (t_{tot}/t_b)}{\ln(t_{tot}/t_a)} \tag{49}$$

$$w = z_a - z_b v^{0.5} \tag{54}$$

$$m_{gb} = m\left(\frac{m_{ga}}{m}\right)^v \tag{76}$$

$$m_{gb} = m_{ga} \exp[0.5 (1 - v) \ln^2 s_{ga}] \quad (79)$$

$$c_{max} = c_{max\ hr} t^q \quad (84)$$

The parameters used in these equations have been arranged alphabetically and are defined as follows:

a = one averaging time,

b = a second averaging time,

c = concentration,

c_{max} = maximum concentration, usually the maximum expected once a year,

exp = base of natural logarithms, 2.718, raised to the power that follows in brackets,

f = frequency, in percent, with which a particular concentration is equaled or exceeded,

h = one given concentration point,

i = a second given concentration point at the same averaging time as h,

ln = natural logarithms, base e,

m = arithmetic mean,

m_g = geometric mean,

n = number of samples,

q = slope of the maximum concentration line on logarithmic paper,

r = rth value in a set of aerometric data ranked from the highest concentration to the lowest concentration,

s_g = standard geometric deviation,

t = averaging time,

t_{tot} = total averaging time, usually 1 year (8760 hours), and

z = number of deviations a point is located away from the median.

EXERCISES

The following exercises are recommended for increasing proficiency with the techniques discussed in this paper. The example used involves only 11 samples in order to reduce the amount of computation needed. It has been assumed that 1-month sulfur dioxide samples have been taken in front of the U.S. Capitol for each month of 1 year and that the concentrations, in $\mu g/m^3$, from January through December are 300, 250, 180, missing, 150, 60, 120, 100, 140, 160, 190, and 220, respectively.

1. What is the arithmetic mean concentration for the year?

2. Calculate the geometric mean by using all values.

3. What is the maximum 1-month observed concentration, and at what frequency should it be plotted on log-probability paper?

4. What is the minimum 1-month observed concentration and at what frequency should it be plotted on log-probability paper?

5. At what frequency should each of the observed values, from January through December, be plotted on log-probability paper?

6. Plot the 11 values on log-probability paper (e.g., Keuffel & Esser Co. paper 46 8040, probability x 2-log cycles).*

7. Use the arithmetic mean and the maximum to calculate the standard geometric deviation (a frequency of 5.5 percent is a z-value of 1.60).

8. Calculate the geometric mean from the calculated standard geometric deviation and the maximum.

9. Use the answers from 7 and 8 to calculate the standard geometric deviation and geometric mean for 1-hour average concentrations.

10. Use the answers from 9 to calculate the expected annual maximum 1-hour concentration.

11. Compare the answers in 9 and 10 with values in Table 14.

12. Plot the expected annual maximum concentration on logarithmic paper as a function of averaging time. Draw the curve through the hourly maximum, monthly maximum, and annual mean. Read the 24-hour maximum from the graph and compare it with the value calculated by using Table 14.

ANSWERS

1. $m = 170\ \mu g/m^3$.
2. $m_{g\ \text{month}} = 156\ \mu g/m^3$.
3. $c_{\text{max month}} = 300\ \mu g/m^3$, $f = 5.5\%$.
4. $c_{\text{min month}} = 60\ \mu g/m^3$, $f = 94.5\%$.
5. 5.5%, 14.5%, 41.8%, missing, 58.2%, 94.5%, 76.4%, 85.5%, 67.3%, 50.0%, 32.7%, 23.6%.
7. $s_{g\ \text{month}} = 1.50$.
8. $m_{g\ \text{month}} = 157\ \mu g/m^3$.
9. $s_{g\ \text{hr}} = 2.17$, $m_{g\ \text{hr}} = 126\ \mu g/m^3$.
10. $c_{\text{max hr}} = 2411\ \mu g/m^3$.

*Mention of a commercial product or company name does not constitute endorsement by the U.S. Environmental Protection Agency.

REFERENCES

1. National Primary and Secondary Ambient Air Quality Standards. *Federal Register.* **36**:8186-8201. April 30, 1971.

2. Air Quality Criteria for Carbon Monoxide. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Washington, D.C. Publication No. AP-62. March 1970.

3. Air Quality Criteria for Particulate Matter. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Washington, D. C. Publication No. AP-49. January 1969.

4. Air Quality Criteria for Photochemical Oxidants. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Washington, D.C. Publication No. AP-63. March 1970.

5. Air Quality Criteria for Sulfur Oxides. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Washington, D.C. Publication No. AP-50. January 1969.

6. Larsen, R. I. Relating Air Pollutant Effects to Concentration and Control. *J. Air Poll. Contr. Assoc.* **20**:214-225, April 1970.

7. Larsen, R. I. and H. W. Burke. Ambient Carbon Monoxide Exposures. APCA Paper 69-167. Presented at the annual meeting of the Air Pollution Control Association, New York City, June 22-26, 1969.

8. Larsen, R. I., C. E. Zimmer, D. A. Lynn, and K. G. Blemel. Analyzing Air Pollutant Concentration and Dosage Data. *J. Air Poll. Contr. Assoc.* **17**:85-93, February 1967.

9. Guidelines for the Development of Air Quality Standards and Implementation Plans. U.S. DHEW, PHS, CPEHS, National Air Pollution Control Administration. Washington, D.C. May 1969.

10. Aitchison, J. and J. A. C. Brown. The Lognormal Distribution. Cambridge University Press, New York. 1966. p. 8.

11. Drinker, P. and T. Hatch. Industrial Dust (2nd Ed.). McGraw-Hill, New York. 1954. p. 194.

12. Larsen, R. I. Determining Basic Relationships Between Variables. Symposium on Environmental Measurements. U.S. DHEW, PHS, Division of Air Pollution. PHS Publication 999-AP-15. Cincinnati, Ohio. July 1964. p. 251-263.

13. Larsen, R. I. A New Mathematical Model of Air Pollutant Concentration, Averaging Time, and Frequency. *J. Air Poll. Contr. Assoc.* **19**:24-30, January 1969.

14. Pearson, E. S. and H. O. Hartley. Biometrika Tables for Statisticians. Vol. 1. Cambridge University Press, New York. 1962. p. 175.

15. Lowrimore, Gene R., statistician, Effects Studies, Environmental Protection Agency. Personal Communication.

16. Hunt, W. F., Jr. The Precision Associated with the Sampling Frequency of Log-Normally Distributed Air Pollutant Measurements. APCA Paper 70-99. Presented at the annual meeting of the Air Pollution Control Association, St. Louis, Missouri, June 14-19, 1970.

17. Stalker, W. W., R. C. Dickerson, and G. D. Kramer. Sampling Station and Time Requirements for Urban Air Pollution Surveys. *J. Air Poll. Contr. Assoc.* **12**:361-375, August 1962.

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